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THE

CHEMISTRY AND METALLURGY

OF

COPPER,

INCLUDING A DESCRIPTION OF THE PRINCIPAL COPPER MINES OF THE UNITED STATES AND OTHER COUNTRIES,

THE ART OF MINING AND PREPARING ORES FOR MARKET,

AND THE

Various Processes of Copper Smelting, &c.,

BY

A. SNOWDEN PIGGOT, M. D.,

ANALYTICAL AND CONSULTING CHEMIST, MEMBER OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, OF THE AMERICAN MEDICAL ASSOCIATION, AUTHOR OF DENTAL CHEMISTRY AND METALLURGY, &C. &C.

WITH ILLUSTRATIONS.

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CAMPBELL MORFIT, M. D., CHEMIST,

THIS WORK IS INSCRIBED

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PREFACE.

Having been engaged for some years in the analysis of ores of copper, and in the determination of chemical questions concerning that metal, in connection with a large and well-appointed smelting establishment, the author has acquired experience which he has thought might be of service to others engaged in the same pursuit. He has also been led to believe that some information, in a form accessible to the masses of our people, on the subject of mines, veins and ores of copper, with the known laws of their occurrence, might be of service in assisting in the development of this very important part of the mineral wealth of our country.

The present work is designed to supply what the author believes to be a desideratum. His aim has been to popularize it sufficiently for the use of those who have not hitherto made the sciences of chemistry and geology a special study, without so neglecting details as to render it of no value to the expert in these studies. How far he has succeeded in this attempt is for the public to judge.

In the chapter on Mining, the author has endeavored to present as complete an account of the various copper regions,

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as was possible in the limited space of a volume like the present. In treating of foreign mines, it has not been intended to give anything like a minute description of them, but simply to present to the reader a sketch of their geology and general results, sufficient for the purposes of comparison with our own mining regions. In reference to the mines of the United States the author would say, that he has endeavored to embody the latest information accessible to him. Those who have attempted to collect similar statistics, are aware of the difficulty of obtaining reliable information, and will pardon any omissions they may detect.

In the chapters on Smelting and Assay of Ores, the object has been to define the principles on which the processes are based, and to describe with clearness and precision, the various methods by which the results are proposed to be attained. It is to be hoped, that in this, as in the other departments treated upon, the work will be found sufficiently full and accurate to serve as a guide to those engaged in adding to the world's production of copper.

A. Snowden Piggot.

40 Bolton Street, Baltimore,
January 20th, 1858.

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ERRATUM.

Page 215, 2d and 3d lines from top, "*Cope*" should read "Cobre."

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CHAPTER I.

CHEMICAL RELATIONS OF COPPER.

COPPER being an abundant metal, easily reduced from some of its ores, and susceptible of a great variety of important applications, might be supposed to be discovered at an early period of the world's history. Accordingly we find it among the few metals mentioned in the Pentateuch. Moses tells us that the antediluvian metallurgist, Tubal Cain, was the father, that is, the instructor or master of all those that work in *brass* and iron. The Egyptians used it largely, and with them, as with other ancient nations, it supplied the place of steel. Hesiod tells us that iron was a late invention, brass being the material out of which the weapons of antiquity were fabricated. The shields, helmets and swords of Homer's heroes were also formed of it. In later times, when iron had superseded the ancient metal, the same name, χαλκευς, originally applied to the armorer, and meaning a worker in brass or bronze, was retained as the appellation of the blacksmith who wrought in iron. The brass of the ancients or χαλκος, a word derived from the Arabic, and signifying any thing capable of being polished, was not the compound to which we apply that name, but a sort of bronze or alloy of copper and tin.

Our English word copper, together with the terms

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used in most of the modern languages to designate this metal, is derived from the Latin *cuprum*, which itself comes from Cyprus, or Kupros, as it was spelt by the Greeks, an island sacred to Venus, where it was extensively mined and smelted in very ancient times. The alchemical title of copper was Venus, and the symbol of the planet was, in that singular old astro-chemical system, applied to the metal.

Copper. Copper is distinguished from all metals, except titanium, by its color, which is a fine brownish red, slightly inclining to yellow. When reduced to a very thin pellicle, it is transparent, and by transmitted light, has a beautiful green color. Films of this kind may be obtained by heating a little oxide or chloride of copper in a glass tube through which a current of hydrogen gas is passed, when the glass is coated by a layer of metal of extreme tenuity, displaying a red color by reflected, and a green by transmitted light. When warmed or rubbed it gives off a disagreeable smell and a peculiar faint nauseous metallic taste. It is susceptible of a high but fugacious polish, as it is extremely liable to tarnish.

Native copper is occasionally found crystallized in regular octahedra. These may also be obtained artificially by allowing fused copper to cool very gradually in a crucible, then breaking the outer crust and pouring out the still liquid metal, when the inner surfaces will be found to be lined with small crystals of this form. The galvanic process of precipitating copper yields the same result. When thrown down from its solutions by other metals, its crystals have usually a cubical form, and are very small.

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Copper is both malleable and ductile. Gold and silver only exceed it in malleability, while in ductility it is surpassed by gold, silver, platinum and iron. It can be beaten into very thin leaves, while it cannot be drawn out to extremely fine wire. In a state of minute division, it welds like gold, a property which has been taken advantage of in the manufacture of medals. Fine copper powder is strongly forced into the die, and an unusually sharp and clear impression is thus obtained. The medal may be afterwards hardened by careful annealing.

It is more tenacious than any of the other metals excepting iron. A copper wire, one-tenth of an inch in diameter, is capable of supporting a weight of 385 pounds. It is soft enough to be cut with a knife, but is more resisting than lead. It is the most sonorous of the metals, and constitutes an important part of those alloys which are used in the manufacture of bells, gongs, &c.

The specific gravity of copper fused in the open air is lower than that of the metal under other circumstances, because some oxygen is absorbed from the air. It reaches only 8.7 or 8.8. Fused under a protecting slag, its specific gravity is 8.91 to 8.921. That of the unignited wire is 8.939 to 8.949; of the ignited wire, 8.93; of flattened wire and well rolled sheet, 8.95 to 8.96.

Copper melts at a full red heat. The fusion point has been stated to be 1996° F.; intermediate between those of silver and gold. At a white heat it burns with a brilliant green flame. At high temperatures below its

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point of combustion it is volatile, and even at its fusing point a small quantity escapes into the atmosphere. In the most carefully managed furnaces, this loss is unavoidable, and has been said to amount to the fourth of one per cent., though bad management will raise it very much above this. It is, however, difficult, if not impossible, to determine with any accuracy the amount of loss from this source, because it cannot be ascertained with precision how much soaks into furnace bottoms and how much is lost in other furnaces in the reduction of refinery slag. All the ores of copper are more or less volatile, and in a furnace without a culvert much metal must necessarily be lost. The author has known 20 tons of fine, impalpable, reddish brown powder, containing on an average 14 per cent. of copper, to be taken out of the culvert of a smelting establishment, as the residuum of about 3000 tons of ore, averaging 22 per cent. This, however, must not be taken by any means as the standard of volatility for ores of copper, because much of this was, in all probability, swept up the chimney mechanically by the strong draught of air.

Commercial copper varies remarkably in purity. Russian copper is generally very nearly chemically pure. Some of the American copper is also very free from impurities. Most of the refined metal, however, in all countries, contains lead, iron and antimony, and the best of it is scarcely ever free from traces of carbon and suboxide of copper. The pig copper of commerce is of course always impure. That from South America is often extremely bad, being not only carelessly smelted and therefore containing the ingredients of the

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ore, but fraudulently mixed with fragments of old iron to increase the weight. Pigs of this metal, which are nothing but bars of iron encased in copper, are occasionally imported into this country from the smelting houses on the west coast of South America.

For many laboratory uses, good commercial copper is sufficiently pure. The turnings are often used, and then it is necessary that they should undergo some little preparation. The grease with which they are commonly contaminated is burned off by heating them to redness in the open air. This cannot, however, be done without coating them with black oxide, which is to be removed by heating them in a current of dry hydrogen gas, until no more steam is given off, and the surface is perfectly pure and free from tarnish of any kind. The metal is then allowed to cool in an atmosphere of hydrogen.

Strips of sheet copper are often used in some analytical processes, such as, for example, Levol's method of ascertaining the quantity of copper in an ammoniacal solution of the black oxide, or Reinsch's test for arsenic. For the former purpose, common sheet copper will answer, provided its surface has been carefully cleansed. For the latter, the author has been in the habit of using the faces of Swiss watches. The enamel is carefully beaten off, and the copper passed through a gold-beater's mill. The surface being then cleansed with dilute acid is extremely sensitive to the smallest traces of the poison in question. Copper gauze is often used for the same purpose.

Perfectly pure copper is obtained by precipitating the

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metal from a solution of chemically pure sulphate of copper, on a surface of copper, by the galvanic process. It is also procured by passing a stream of hydrogen through a heated tube containing absolutely pure oxide of copper. It is then in the form of a red powder which, however, readily assumes the metallic lustre on being rubbed between two hard polished surfaces.

At ordinary temperatures, copper does not tarnish when exposed to perfectly dry air or oxygen gas. In moist air, especially if acid vapors be present, it becomes rapidly coated with a layer of oxide, which absorbs carbonic acid from the atmosphere and is converted into a green basic carbonate, mingled with oxide, commonly known as *verdigris*. Every imaginable tint of olive green is produced by the variable mixtures of these two ingredients. A surface of metallic copper, moistened with acid and exposed to the atmosphere, combines with the oxygen of the air, and the resulting oxide unites with the acid, producing a neutral salt, which, by the action of its oxygen upon the metal, is ultimately reduced to basic salt adhering firmly to the metal.

In a solution of ammonia, copper is also oxidated, a blue solution resulting. Dilute solutions of chloride of sodium (common salt) dissolve copper very rapidly, while concentrated solutions of the same salt exert little or no effect on it. It has been suggested that this action is a galvanic one, circles being formed between the copper and the small particles of foreign metals and other impurities existing in it, though it is not easy to see how the dilution renders the solution more active.

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At a white heat copper feebly decomposes steam, converting it into oxygen and hydrogen. At common temperatures this change does not take place. Acids even do not enable it to effect the decomposition of water at the ordinary temperature. In a state of fine division, copper is dissolved by hydrochloric acid, while in larger masses this reagent scarcely affects it. Its action is probably dependent upon the oxygen of the atmosphere. Strong sulphuric acid, especially when aided by heat, dissolves it, with the evolution of sulphurous acid gas, a phenomenon which shows that the oxidation of the metal takes place at the expense of the acid itself, and not of the water with which it is combined. Cold nitric acid, of any degree of concentration, dissolves it rapidly, with the evolution of copious red fumes of hyponitric acid, resulting from the action of atmospheric air upon the deutoxide of nitrogen.

Fatty matters also predispose copper strongly to unite with oxygen. Hence vessels of copper can only be used with safety for a very few culinary purposes, as its compounds are decidedly poisonous.

The symbol of copper is Cu. Its equivalent, as determined by the reduction of the black oxide by hydrogen, is 31.71 on the hydrogen, and 396.7 on the oxygen scale.

Uses of Copper. Copper is used for a great variety of purposes in the arts. One of the most extensive of its applications is that of sheathing, and bolts for ships. It is of service here, because it is less readily acted upon by sea-water than any other of the cheap metals, and because the friction of the water upon it is less than it

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would be upon wood. Iron cannot be substituted for it even in a ship's bolts, because the sea air is sufficiently impregnated with salt to corrode this metal with great rapidity.

It is used also to alloy the precious metals. These are too soft to be worked to any advantage without the introduction of copper, which gives the necessary hardness, without diminishing the lustre, and if proper precautions be taken, without impairing the color of the alloys. It is consequently the common alloy in jewelry and in gold and silver coinage. Its combinations with the cheaper metals, which are very important, will be described in another place.

It is also peculiarly adapted to boilers in which saline waters are to be used, as the incrustations are not so adherent as they are to iron boilers, neither are they so corrosive in their action. They are easily removed, and leave the surface of the boiler perfectly clean and bright, so that the thickness of the boiler not being diminished, there is none of that danger of explosion which attends the use of iron boilers under similar circumstances.

As copper was one of the earliest, so it continues to be the best material on which to execute artistic engravings. Steel has been lately substituted, from motives of economy, as it is capable of yielding a larger number of impressions, but it is not susceptible of that mellowness and richness of effect to be obtained from copper. Etchings are made upon the surface by covering it with a varnish, and then engraving through this with a sharp tool. The shadows are produced by cutting into the plate with gravers and deepening the impressions with

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acid, while varnish is spread over the lights and middle tints to protect them from the corrosive action. The rationale of this is that, when these plates are put upon the press, the darkest portions of the impression correspond with the broadest and deepest furrows upon the surface of the copper.

NON-SALINE COMPOUNDS OF COPPER.

Oxides of Copper. When copper is heated in the air, it is covered with a red film of suboxide which passes gradually into the black or protoxide. When copper is fused in the atmosphere, tarnishes, of various hues of yellow, red, purple and black, form on the surface. These indicate various admixtures of the two oxides with metal, and may be conveniently seen on the surface of ingots sent to market. When these have been allowed to cool too long in the air after being cast, they are invariably coated with a black layer. When they have been early immersed in the water, the tarnish is either an orange yellow, a fine ruby red, or a mixture of the two. It is upon the proper management of this that the preparation of Japan copper depends. This is cast in small moulds, and the moment it becomes consolidated, it is thrown into water where it becomes covered with the well known beautiful red film of suboxide. Heated in oxygen or the flame of the compound blowpipe, copper burns with a rich green flame, and is wholly converted into black oxide. Its tarnish, gradually acquired from the atmosphere, is at first, a warm, deep brown, which gradually passes into the dark olive-green,

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so highly prized by antiquaries, a color produced by the mixture of the carbonate with the two oxides.

Copper forms four definite compounds with oxygen.

1. The suboxide, or red oxide, Cu_2O.
2. The protoxide or black oxide, CuO.
3. The binoxide, CuO_2.
4. Cupric acid the composition of which is undetermined.

*Suboxide of Copper.** Cu_2O, 71.42. The native dioxide will be described in the next chapter. It is often found as a product of furnace operations. Much of the slag from a refining furnace is composed of this oxide. It then is of a deep red color, oftener porous than compact, and mingled with various impurities.

It may be obtained by several processes.

1. Ignite in a well covered crucible a mixture of 31.71 parts of metallic copper with 39.71 parts of black oxide. This mixture aggregates at a high temperature and a red fused mass of the suboxide is obtained. An analogous process of reducing the black oxide is to heat to redness in a carefully closed crucible, alternate layers of fine copper sheet and black oxide.

2. Heat in a crucible a mixture of subchloride of copper with carbonate of soda, and then dissolve out the chloride of sodium and the excess of carbonate of soda by water. The suboxide is left as a deep red crystalline powder. A very fine metallic pigment has been

* It is proper to state here that this suboxide is called by some the *protoxide*, while the *black oxide* is rated as a *peroxide*. The form also adopted in the text, however, is that which is now universally adopted by chemists.

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made by a process resembling this. Sulphate of copper is mixed with carbonate of soda, in the proportion of 100 parts of the former to 59 of the latter. These mixed salts are fused in their water of crystallization at a low temperature, and the heat is continued till the mixture is dry, when 25 parts of finely divided metallic copper are mixed with and the whole is heated to whiteness, in a covered crucible, for twenty minutes.

3. A solution of some salt of the black oxide is mixed with a solution of grape sugar, (cane sugar may be converted into this variety by boiling it with a few drops of dilute sulphuric acid.) Potassa is then added till the precipitate first formed is completely re-dissolved, forming a violet-blue fluid. This is boiled for some time, when the suboxide is deposited in small bright red crystals.

This oxide is always formed when a large quantity of metallic copper is fused under scoriæ sufficiently thin to admit a little atmospheric air. It is often found on the sides of refining furnaces mixed with the black oxide, and then the mass is crystalline in its texture, dark gray in color, with metallic lustre, and flecked with splendid ruby-red, semi-transparent particles.

This compound varies in color from a brownish copper-red to a pure carmine tint. In a dry atmosphere it may be kept a long time, but moisture rapidly peroxidates it. Heated to redness, it is converted into the black oxide. The acids act upon it variously. Most of them decompose it into a salt of the black oxide and metallic copper. Strong nitric acid oxidates it with the evolution of binoxide of nitrogen. Hydrochloric

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acid dissolves it, forming a colorless solution, from which the alkalies and their carbonates throw down yellow and red precipitates, and ferrocyanide and iodide of potassium white or brownish ones. Ammonia dissolves it to a colorless fluid, which rapidly becomes blue when exposed to the air, in consequence of absorption of oxygen. This blue solution is decolorized again by being allowed to remain in a well-closed bottle in contact with strips of metallic copper.

Fused with glass, this oxide forms a fine rich ruby-red, when proper care is taken to prevent oxidation. A little metallic tin is often mixed with it for this purpose. Its coloring power is very intense, so that an exceedingly thin film may be blown out as a covering to a vessel of transparent glass. The outer film may be then cut through, and various forms obtained in colorless glass. Pastes are also colored by it to imitate the ruby and the garnet.

Hydrated suboxide of copper, $4Cu_2O,HO$. This is prepared by decomposing the subchloride with potassa or soda. It is a yellow powder, which rapidly absorbs oxygen from the air, and must, therefore, be dried *in vacuo*.

The suboxide is a feeble base, forming salts, which will be presently described.

Oxide or Protoxide of Copper, Black Oxide. CuO. 39.71. This oxide is found native, and is always formed when copper is heated in the air, or precipitated from its solutions by alkalies. The author has, in his collection, specimens of this oxide in acicular crystals, lining the cavities of fire-brick from the sides

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of a refining furnace, through which it had passed either by filtration or sublimation, probably the latter.

It is prepared by roasting copper filings, or calcining the finely divided copper obtained from the ignition of the acetate, but better by igniting the nitrate. Several methods of performing this ignition have been suggested. The most common is to heat the nitrate to whiteness in a Hessian crucible. An improvement on this process has been made by heating the salt in a vessel made by striking up an entire piece of sheet-copper. This vessel is, indeed, corroded by the process, but it furnishes additional portions of oxide. Another method is to mix the nitrate with half its weight of copper filings, to expose the mixture to the air, and to ignite the basic nitrate thus obtained. The object of the last named modifications is to increase the yield, and so to economize the acid. Another method is to ignite the hydrated oxide obtained by precipitating copper salts with potassa.

Oxide of copper, as ordinarily seen, is a powder ranging in tint from a deep brown to a bluish black. When strongly heated, it fuses, and, at a very high temperature, loses some of its oxygen, being converted into mixture of the black and red oxides. The fused oxide is a deep, lustrous, iron-gray mass. Fused with hydrate of potash or soda, it forms a blue or green mass, easily decomposed by water. When this fused mass is allowed to cool slowly, the oxide crystallizes in tetrahedra, which are easily obtained by dissolving out the alkalies with water.

Deoxidating agents, such as protoxide of iron, proto-

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chloride of tin, and organic matters at a boiling temperature, convert it into dioxide. Hydrogen and carbon, aided by heat, easily reduce it to metallic copper. The former of these agents effects the deoxidation at a heat below redness.

This oxide is insoluble in water, but dissolves in acids, forming important salts. All the valuable salts of copper have this oxide for their base.

The oxide of copper is extensively employed in organic analysis as a source of oxygen; the substance to be analyzed is mixed with the perfectly dry and warm oxide, introduced into combustion-tube, and gradually heated to redness. The hydrogen and carbon are converted into water and carbonic acid, which are collected in a proper apparatus.

This oxide is used to color glass, green or blue. It is employed in the manufacture of artificial gems to imitate the *emerald*, for which purpose it is usually mixed with chrome or sesquioxide of iron.

Hydrated Oxide of Copper. CuO,2HO. This is obtained as a pale blue precipitate by adding excess of a solution of potassa to a solution of any copper salt. Should too little alkali be used, a basic salt will be formed. The water is very feebly united with this oxide, for should the blue precipitate be boiled with its supernatant solution, it is converted into the heavy, anhydrous black oxide. The same change takes place, but more slowly, when this hydrated oxide is exposed to the air. In order, therefore, to procure the hydrated oxide of the formula given above, it must be dried under the exhausted receiver of an air-pump.

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The pigment known as blue verditer, has this oxide for its basis. It dissolves readily in acids, and in water of ammonia. With the latter liquid it forms a fine purplish blue solution, called *celestial water*. Two definite compounds with ammonia with oxide of copper and water have been obtained. Their formulæ are $CuO,NH_3,4HO$, and $3CuO,2NH_3,6HO$.

The hydrated oxide dissolves to a slight extent in cold concentrated solutions of potassa and soda, forming blue liquids, which deposit the black oxide when heated.

It is by the reactions of this oxide that copper is usually detected and estimated. For a description of these reactions, the reader is referred to Chapter III.

Binoxide or Peroxide of Copper, CuO_2. When the hydrated protoxide of copper is treated with peroxide of hydrogen, the blue substance assumes a brownish yellow color, and, by the abstraction of another atom of oxygen from the fluid, is converted into a deutoxide. A very slight elevation of temperature decomposes it into protoxide and oxygen: acids have the same effect. Under water it undergoes spontaneous decomposition, and can only be dried over sulphuric acid *in vacuo*. It is of no special interest.

Cupric Acid. When finely divided copper is fused with hydrate of potassa and nitre, or when hydrate of copper is dissolved in hypochlorite of potassa, a salt is obtained in which a combination of copper with oxygen seems to play the part of an acid. The solution is blue, and is very easily decomposed. Heat precipitates from it black oxide of copper, oxygen being at the same time evolved. By reason of this instability, this acid

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has never been exhibited in a separate state, and therefore no atomic constitution can be assigned to it.

Copper and Hydrogen. Cu_2H. Wurtz has obtained a compound of copper and hydrogen, by heating, at a temperature of 158°, a solution of sulphate of copper with hypophosphorus acid.

Thus prepared, the hydride of copper is a bright brown powder, which oxidizes in the air. At about 140° F. it decomposes, being resolved into metallic copper and hydrogen gas. Hydrochloric acid decomposes it, forming protochloride of copper which dissolves, while hydrogen gas is liberated.

Copper and Nitrogen. By passing a current of dry ammoniacal gas over oxide of copper (CuO) heated to 599°, a nitride of copper has been obtained by Schrötte, who assigns to it the formula Cu_6N. It is, however, mixed with excess of oxide of copper, which is dissolved out by ammonia.

It is a deep green amorphous powder, which is decomposed with some violence at a heat below redness. It dissolves in hydrochloric acid, yielding chloride of copper and sal-ammoniac.

COPPER AND SULPHUR.

There are a number of combinations of copper and sulphur; but those best understood are the *subsulphide*, corresponding with the dioxide and the *sulphide*, answering to the protoxide.

Subsulphide of Copper. Cu_2S. In the vapor of sulphur copper burns brilliantly, and this sulphide is the result of the combustion. It is sometimes found in

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copper furnaces, crystallized in regular octahedra. In the laboratory, it is prepared by mixing three parts of sulphur and eight of copper turnings, heating them till combination takes place with evolution of heat and light, grinding the substance thus obtained to powder, and heating again with a little sulphur, in order to mineralize the remaining metal.

This sulphide is much more fusible than metallic cop- and is not decomposed by heat. When roasted in the air, it is converted partly into sulphate and partly into oxide of copper. It cannot be reduced by hydrogen, and when heated with carbon, it is only partially reduced to metallic copper. Fused with caustic alkalies and cyanide of potassium, metallic copper is separated. When a mixture of the sulphate and subsulyhide of copper is heated together, decomposition takes place, metallic copper and sulphurous acids being the results. Hydrochloric acid does not attack it, but aqua regia dissolves it.

Sulphide of Copper. CuS. When hydrosulphuric acid or a soluble sulphide is introduced into a solution of a copper-salt, a black precipitate of sulphide of copper falls. This must be washed with sulphureted hydrogen water, and dried rapidly over sulphuric acid *in vacuo*.

It is a black powder, which, when exposed to the air, especially if damp, becomes dusky green from absorption of oxygen and conversion into sulphate of copper. Heated out of contact with atmospheric air, it loses one half its sulphur, and is converted into the subsulphide. Roasted in the air, it gives off sulphur and sulphurous acids, and is changed into a mixture of the oxide and sulphate of copper.

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Boiling sulphuric acid does not attack it; hydrochloric acid has hardly any action upon it, but nitric acid dissolves it, separating the sulphur and forming nitrate of copper which remains in solution. It is slightly soluble in *yellow* sulphide of ammonium,* but not in sulphide of potassium.

HIGHER SULPHIDES OF COPPER are said to have been obtained by the action of the polysulphides of the alkaline metals upon copper salts.†

An *oxysulphide*, of the formula 5CuS,CuO,HO, is said, by Pelouze, to be precipitated when a boiling solution of nitrate of copper, mixed with excess of ammonia, is treated with a soluble sulphide.

COPPER AND PHOSPHORUS.

When finely divided copper is heated in the vapor of phosphorus, there is obtained a gray, brittle metallic mass, containing about 20 per cent. of phosphorus.

A phosphide of the formula Cu_2P is formed by passing a current of hydrogen over heated phosphate of copper. Another phosphide, Cu_3P, falls as a black precipitate when phosphureted hydrogen is passed through a copper solution of a copper-salt. There are other phosphides, but they have not been studied.

* When sulphide of ammonium is first prepared, it is colorless, but after a time it becomes yellow, in consequence of the separation of sulphur which dissolves in the liquid. Its properties are now somewhat changed; hence the particularizing of this form of the sulphide.

† The alkaline metals are sodium and potassium, and the term "polysulphides" is used to denote those sulphurets of these metals which contain several atoms of sulphur to one of metal.

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SALTS OF COPPER.—HALOID SALTS.*

Subchloride of Copper. Cu_2Cl. There are several methods of preparing this compound.

1. A solution of chloride of copper is boiled over metallic copper until its green color changes to brown. The clear liquid is then decanted and mixed with a large quantity of water, which precipitates the subchloride. This precipitate must be rapidly washed with boiled water, and kept under a layer of water in a well-closed bottle. When a strip of copper is used, instead of copper turnings the subchloride is deposited in white tetrahedral crystals upon the surface of the metal.

2. A solution of chloride of copper is precipitated with a concentrated solution of protochloride of tin,

* The old definition of a salt was a combination of an acid with a base. Subsequent investigation, however, proved that, in the direct formation of many salts, there was a decomposition of both base and oxide. Thus, when hydrochloric acid is poured upon soda, this double decomposition is effected by the oxygen leaving the soda and the hydrogen abandoning the acid. These two elements thus combine to form water, while the chlorine and the sodium unite to form a *chloride of sodium*, and not, as it was formerly called, a muriate of soda. As there is a large number of these salts, which correspond with chloride of sodium or common salt in their constitution, the name *Haloid salts*, (from the Greek word ἁλς, signifying common salt,) has been applied to the entire class. Their characteristic is that they are formed by a direct union of two simple bodies, or of compound radicals with one another, or with a simple body—commonly a metal.

The *oxysalts* are still regarded by most chemists as constituted according to the old formula, though some have classified them under the same head with the haloids, altering the acid formula.

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containing a little free acid. The subchloride goes down. The reactions are shown by the formula,

$$2CuCl+SnCl=Cu_2Cl+SnCl_2.$$

This chloride may be obtained in small tetrahedral crystals by dissolving the amorphous compound in hot hydrochloric acid, which deposits the crystals as it cools.

3. When the protochloride is heated, it parts with half its chlorine, and is converted into anhydrous subchloride.

4. When chloride of mercury is distilled with copper filings, the mercury passes over, and this chloride is left behind. Boyle, who procured it in this way, called it *resin of copper*, from its resemblance to common resin.

This chloride varies in its tint according to its mode of preparation. As usually obtained, it is white, but may also be yellow or dark brown. It is fusible at a heat just below redness, (752° F.) and volatile at a higher temperature. It soon changes in the air, in consequence of the absorption of oxygen, and becomes converted into a green mixture of hydrated oxide and chloride. It is nearly insoluble in water, but dissolves in hydrochloric acid, forming a brown liquid, from which, as already stated, water precipitates the subchloride. It is also very soluble in ammonia, forming with it a colorless solution. This property renders it a valuable agent in eudiometric analyses, for separating oxygen from mixed gases. A solution of common salt also dissolves it. Alkalies decompose it, precipitating from it the suboxide.

Cholride or Protochloride of Copper. CuCl. When finely divided copper is heated in an atmosphere of

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chlorine gas, it takes fire, and forms the *anhydrous* chloride of copper. This is a yellowish brown substance, which is decomposed by heat into chloride and the subchloride.

The *hydrated chloride* is prepared by dissolving the oxide in hydrochloric acid, or the metal in aqua regia, evaporating and allowing the solution to crystallize. It forms beautiful green needles, which are very deliquescent and easily soluble, both in water and alcohol. When the latter solution is kindled, it burns with a beautiful green flame. The solution is blue when diluted, but a rich emerald green when concentrated, or when mixed with excess of hydrochloric acid. The anhydrous chloride absorbs three equivalents of ammonia, and is converted into a blue compound.

Oxchlorides of Copper. There are three combinations of the chloride and oxide of copper, containing one equivalent of the former to two, three or four equivalents of the latter.

Brunswick Green. CuCl,3CuO,4HO, is the most interesting of these compounds. This well-known pigment is made by digesting hydrated oxide of copper in a solution of the chloride, or more commonly by exposing plates of copper moistened with hydrochloric acid or sal-ammoniac to the action of the atmosphere. It is a green powder, soluble in acids but not in water. On the application of heat it loses water and becomes brownish black.

When chloride of copper is precipitated by a small quantity of potassa, a pale-green powder is thrown down having the composition CuCl,2CuO,4HO. Heated strongly it becomes black, all the water being driven off,

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leaving CuCl,2CuO. Kept at 208°, a brown compound is left, CuCl,2CuO,HO. The black substance moistened becomes CuCl,2CuO,3HO.

Double Chlorides The double *chloride of copper and ammonium*, $CuCl,NH_4Cl,2HO$, is obtained by mixing saturated solutions of chloride of ammonium and chloride of copper, or by precipitating with ammonia a solution of chloride of copper containing excess of hydrochloric acid. It crystallizes in beautiful blue rhombs, soluble in water, efflorescent in the air, changing into a greenish-white powder.

When hot chloride of copper is saturated with ammoniacal gas, ammonia-chloride, $CuCl,NH_3$, is formed, which is decomposable by water. This dissolves a biammonia-chloride, $CuCl,2NH_3$, which crystallizes in dark-blue prisms, having the formula $CuCl,2NH_3,HO$. A tri-ammonia-chloride, $CuCcl,3NH_3$, also exists.

A double *chloride of copper and potassium* is formed by mixing strong, hot solutions of the two chlorides. While cooling, the solution deposits blue octahedra, belonging to the quadratic system, and having the formula KCl, CuCl,2HO. The subchloride, used instead of the chloride, furnishes a double salt, crystallizing in anhydrous octahedra of the regular system.

Bromide of Copper. CuBr. Oxide of copper dissolved in hydrobromic acid and evaporated, forms green crystals of the form CuBr,5HO, which by heat separate into bromide and subbromide, Cu_2Br. Dry bromide absorbs ammonia, leaving $CuBr,5NH_3$. There are several other ammonia-bromides and a basic salt, but none of any particular interest.

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Diniodide of Copper. Cu_2I. When a solution of iodide of potassium is added to another of blue vitriol, one half the iodine separates, sulphate of potassa remains in solution, and a brownish-white subiodide of copper, mixed with finely divided iodine, is precipitated. The latter is washed off with alcohol. The sub-iodide is fusible and easily decomposed by nitric and sulphuric acids and by alkalies. The iodide has not been separated. A blue ammonia-iodide, however, exists of the formula $CuI,2NH_3,HO$.

Subfluoride of Copper. Cu_2,Fl_3. Hydrofluoric acid brought in contact with hydrated suboxide of copper converts it into a fusible subfluoride. The silico-subfluoride $3Cu_2Fl,2SiFl$, resembles it in color and character.

Terfluoride of Copper. $CuFl_3$. Hydrofluoric acid forms with black oxide of copper a blue solution, from which this fluoride separates in crystals containing two equivalents of water. It forms with the alkalies and alumina, green soluble double salts. An *oxyfluoride* ($CuFl,CuO,HO$) is formed by treating the blue fluoride with hot water.

A *borofluoride* is obtained by decomposing sulphate of copper with borofluoride of barium. It separates in blue deliquescent crystalline needles of the form CuF,BFl_3.

The *silico-fluoride* is in blue prisms containing twenty-one equivalents of water, two of which are separated by the efflorescence of the salt.

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AMPHID SALTS.*—OXYSALTS.

SALTS OF THE SUBOXIDE. Salts of the suboxide are obtained by dissolving the suboxide in dilute acids.

Sulphite of the Suboxide of Copper—Sulphite of Copper. Cu_2O,SO_2. When sulphurous acid is poured upon hydrated oxide or carbonate of copper, a double decomposition ensues, which may be understood by the formula $3CuO+2SO_2=CuO,SO_3+Cu_2O,SO_2$. Sulphate of copper is formed at the expense of one part of the oxide and is dissolved, and the remaining suboxide unites with the residual sulphurous acid, forming the subsulphite under consideration. It is also obtained by heating a mixture of sulphate of copper with sulphite of soda.

It is a brilliant red crystalline powder, unchangeable when dry, soluble in hydrochloric and sulphurous acids and ammonia, but insoluble in water. Boiling decomposes it, and sulphuric acid exerts the same action upon it.

* This term is derived from αμφι, "both," and used to denote those salts in which both base and acid are double, and contain the same element. Thus sulphate of copper is written CuO,SO_3, and is regarded as a compound of oxide of copper and sulphuric acid, of both of which oxygen is an essential constituent. Such salts are called *oxysalts*, but oxygen is not the only simple body which plays this part. In sulpharseniate of potash, for example, sulphuret of potassium is the base, and sulpharsenic acid the acid of the salt, which has the formula $2Ks,AsS_3$. The latter is a *sulphacid*, the former a *sulpho-base*, and the compound a *sulpho-salt*. Selenium and tellurium act in the same manner. To include these salts and others analogous to them which may be discovered, it was necessary to find some generic term. To meet this Berzelius suggested the above name, which at present seems perfectly satisfactory.

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There is an insoluble double sulphite of copper and potassa.

Hyposulphite of Suboxide of Copper, obtained by treating the sulphate with hyposulphite of lime, is a colorless solution. It forms several double salts with potassa and soda.

Silicate of Suboxide of Copper. This is the substance which forms the coloring matter of red glass. It is sometimes found in the quartz which surrounds native copper.

A *subacetate of copper* is found as a white sublimate lining the upper part of the retort, after the distillation of acetate of copper.

Reactions of Salts of the Suboxides. The soluble subsalts have colorless solutions from which the fixed alkalies throw down the base as a reddish-yellow precipitate. Ammonia produces the same precipitate, but rapidly dissolves it, forming a colorless solution, which soon becomes blue in the air, from absorption of oxygen and consequent change of the suboxide into oxide. Sulphydric acid (sulphureted hydrogen) throws down from these salts the black sulphide of copper.

For the study of these reactions the subchloride is the proper salt to select.

SALTS OF THE PROTOXIDE.

Reactions of Salts of Black Oxide. The hydrated salts of the black oxide with colorless acids are blue or green, the anhydrous salts are white. They are obtained usually by dissolving the oxide or the carbonate in acids.

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Caustic fixed Alkalies precipitate a voluminous, pale blue, hydrated oxide of copper, which, as we have already said, changes to a black, heavy anhydrous oxide when the solution is boiled over it. It is insoluble in alkaline solutions when they are dilute, but dissolves in them when concentrated, giving them a blue tint.

Ammonia throws down the same precipitate, but a slight excess of this reagent redissolves it, forming a magnificent blue solution, containing a double salt of copper and ammonia. Caustic potassa precipitates from this solution all its copper as hydrated oxide.

Sulphydric acid and the *sulphydrates* throw down the black sulphide of copper. This is insoluble in the alkaline sulphides, excepting in the sulphide of ammonium, which dissolves it to a very slight extent.

The *carbonates of potash* and *soda* throw down a greenish-blue precipitate, which is a mixture of the hydrated oxide and the carbonate.

Ferrocyanide of potassium throws down a fine mahogany or chesnut-brown precipitate. In extremely dilute solutions it only tinges the fluid of a purplish-brown.

Albumen forms with copper an insoluble yellowish-white precipitate, which has been shown by Orfila to be inert, so that albumen may be used as an antidote in cases of poisoning by copper.

Metallic iron or *zinc* throws down metallic copper as a brown powder or in crystalline flakes. In dilute solutions these reagents are only tinged with a superficial coating of copper.

Borax, and vitreous fluxes generally, fused with cop-

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per salts, are green when warm, but become *blue* on cooling. If a bead so colored be heated in the inner flame, especially after a little tin has been added to it, it is reduced, and shows the fine ruby-red of the suboxide. When heated a long time it is reduced to metal. This reduction is easily accomplished by mixing the substance with carbonate of soda and heating it upon charcoal. The bead then rubbed up with water in a porcelain or glass mortar will exhibit little red spangles of metallic copper.

The delicacy of some of these tests is remarkable. A clean, polished rod of *iron* is stained with a solution containing only one part of copper in 150,000 of water. Iron wire is best adapted for this test. Steel is not so sensitive. The iron will indicate the presence of copper in a still weaker solution if it be made part of a miniature galvanic battery, by wrapping a coil of fine platinum wire around it. *Sulphureted hydrogen* gives a brown tint in a solution of one part of copper in 100,000 of water. *Tincture of guiacum* gives a blue tint, changing to green when only one part is diffused through 450,000 of water. *Ferrocyanide of potassium* colors ten gallons of water containing only one grain of copper.

Sulphate of Copper. This salt is a common product of mines of sulphuret of copper. The ore is oxydized by the joint action of air and moisture, and the water which trickles over it washes off the newly formed sulphate. This natural process has been imitated by manufacturers who calcine the native or artificial sulphuret. The latter is obtained by heating three

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parts of copper with one of sulphur, till the two combine. The roasting is sometimes carried on in the same furnace with the sulphuration. The fragments of old sheathing, which has been rendered useless by the corrosion of salt water, are heated to a dull-red in a reverberatory furnace, the doors are then closed and sulphur thrown in from above. As soon as the combination has taken place, the doors are opened to admit air, when the roasting commences; a portion of sulphur burns off, and the rest of the sulphuret is oxydized to proto-sulphate of copper. After the roasting has been completed, the remaining sulphate is lixiviated. When the last-mentioned plan is adopted, the sulphatized sheets are hung in boilers filled with water acidified with sulphuric acid, till the sulphate is dissolved. The sheets are then returned to the furnaces and the same processes are repeated till the copper is exhausted. The addition of sulphuric acid increases the product by dissolving some oxide which has escaped the acid of the roasted sulphuret. The solutions are evaporated and crystallized.

Obtained in either of these modes, sulphate of copper is always impure, containing more or less iron, and sometimes traces of other metals. The quantity of iron contained in the sulphate made from the roasted ore varies greatly with the temperature at which it has been calcined. At a very low heat sulphate of iron only is formed; at a bright red this salt is decomposed, and to a considerable extent rendered insoluble. If then the heat be sufficiently raised, this impurity will be very greatly diminished, though not entirely god rid of.

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In the arts it is not always necessary to have a blue vitriol entirely free from iron. If it be desired, however, its purification may be accomplished by heating it to a dull redness with access of air, when nearly all the iron will be rendered insoluble, and a portion of the copper too will be left behind as oxide. On lixiviating the mass we obtain a sulphate of copper, containing little more than a trace of iron. The residuum may be treated with sulphuric acid and the copper obtained from it by precipitation with scraps of metallic iron.

Another method of preparing it is to moisten copper-filings with sulphuric acid, to expose them to the atmosphere, and to continue this process till the copper is entirely converted into sulphate.

A modification of the process which yields an excellent article is the following. The best commercial copper is treated with sulphuric acid diluted with one-half its weight of water; sulphurous acid is disengaged, the copper being oxidated at the expense of the oil of vitriol, and sulphate of copper is formed. To rid this of a little sulphate of iron, it is evaporated to dryness, and a little nitric acid is added towards the close of the operation. This converts the iron into sesquioxide, which is insoluble in water. The iron remains behind as basic sesquisulphate, when the dry mass is lixiviated; only a very small portion of it entering into the solution. It is said that this is totally precipitated by boiling with carbonate or hydrated oxide of copper.

This salt is also procured in large quantities in the process of parting gold and silver, and in the refining of old silver coins. In these, independently of the copper

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contained in the coins themselves, a large quantity is furnished by the liquor which floats over the precipitated silver, resulting from the solution of the copper used to precipitate that metal.

Sulphate of copper is obtained perfectly pure by dissolving pure oxide in pure sulphuric acid.

Pure hydrated sulphate of copper is an azure blue salt, crystallizing in elongated rhombs,* of the doubly oblique rhombic or triclinate system. These contain 32 parts of oxide of copper, 32 of sulphuric acid, and 36 of water in the hundred parts, and may be expressed by the formula $Cu,SO_3,5HO$. A small quantity of iron is recognized by the greenish cast it gives to the crystals, especially to their effloresced surfaces. The presence of iron and zinc in the salt is, however, better detected by a brief and simple analytical process. A stream of sulphureted hydrogen is passed through a solution of the salt, previously acidified, until all the copper is precipitated as sulphide. This is filtered off, the filtrate boiled with the addition of a few drops of nitric acid, and after it has cooled the iron is precipitated by excess of ammonia. After separating the sesquioxide of iron by filtration, the clear liquid is tested for zinc with sulphide of ammonium, which throws down a white sulphide of zinc.

Exposed to a dry atmosphere the salt effloresce parting with two equivalents of water. At 212° it loses four equivalents, but retains the fifth with more tena-

* These crystals are sometimes opaque in spots, in consequence of some of the sulphate being deposited without its water of crystallization. This is especially the case when they are deposited from a strongly acid solution.

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city. For this reason, the last equivalent has been reckoned by some chemists as basic water, the formula $CuO,SO_3,HO+4HO$, has been assigned to it. At from 390° to 430° this water of constitution is expelled, leaving the anhydrous salt a dirty-white pulverulent mass. At a still higher heat it is decomposed, being resolved into sulphurous acid and oxygen, which escape, and black oxide of copper which remains behind. The anhydrous salt has a strong affinity for water, combining with it very energetically and resuming the blue tint of the hydrated salt.

The crystallized sulphate is soluble in four parts of cold and two of boiling water. The solution is blue with an acid reaction, and an unpleasant metallic taste. It is insoluble in alcohol. Like the other salts of copper, it is poisonous to men and animals.

"According to Kane, crystallized sulphate of copper, when dissolved in hydrochloric acid, causes considerable depression of temperature, and yields a green liquid, from which chloride of copper alone is deposited upon evaporation, provided, not less than one equivalent of the acid has been used for each equivalent of salt; in allowing the crystals to remain for some time with the mother-liquor, which contains all the sulphuric acid, crystals of blue vitriol are reproduced. Powdered crystals of sulphate of copper eagerly absorb hydrochloric acid gas, evolving much heat and losing water; a green mass is obtained, which is very deliquescent and fumes in air."—*Abel & Bloxam.*

Sulphate of copper combines in various proportions with the isomorphous sulphates of zinc, iron and copper.

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With iron especially, this combination takes place with great readiness. Mixed solutions of the two sulphates crystallize together, and the resulting crystals contain variable proportions of the three salts. A crystal of sulphate of copper grows, indeed, as readily in a solution of sulphate of iron as in its own mother-liquor. It may be dipped alternately into concentrated solutions of the two salts, and it will continue to increase, the layers of the green and blue vitriol remaining quite distinct, and being easily distinguished by their color. Sulphate of magnesia also forms double salts with sulphate of copper. In all these cases, the double salts contain five equivalents of water when the copper-salt is in excess, and seven when the other sulphate predominates.

The specific gravity of this salt is 2.274, water being the standard of unity. Its water of constitution is occasionally replaced by an alkaline sulphate, a crystallizable double salt being the result.

Uses. Sulphate of copper is largely employed in *medicine.* It is used as an emetic, a tonic, an astringent, a styptic, and a feeble escharotic. In *dyeing* it is employed to develop the various colors of which copper is the basis, and as a reserve in the cold indigo vat. In the *electrotype* process it is used for taking copies of medals in metallic copper. It is the salt usually selected by the manufacturer of blue verditer, Scheele's green, and other pigments of copper. It is sometimes mixed with copperas in making ink; but this is a very bad practice, as it does not materially improve the color of the ink, and renders it very corrosive in its action on steel pens. Anhydrous sulphate of copper is used to deprive alcohol of water.

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Basic Sulphates. Three have been described, of the formulas, $3CuO,SO_3,2HO$; $4CuO,SO_3,4HO$; and $5CuO,SO_35HO$. The second of these is the mineral *brochantite.* They are prepared by precipitating the sulphate just described with a small quantity of alkali, by digesting fresh carbonate or hydrate of copper in a solution of blue vitriol, or by exposing ammonia-sulphate to the air. They are pale green, insoluble, easily decomposed by heat into water, sulphate, and oxide of copper. Kane says that by precipitating blue vitriol with caustic potassa, he obtained another basic salt, the composition of which is, $8CuO,SO_3,12HO$.

Ammonia Sulphates of Copper. There are several double salts of copper formed with ammonia and potassa. The ammoniacal double salts vary much in color and composition.

When solutions of the two sulphates of copper and ammonia are mixed and duly concentrated, we obtain light blue, very soluble crystals of the formula $NH_4O SO_3,CuOSO_3,6HO$. When carbonate of ammonia and sulphate of copper (three parts of the former, and two of the latter) are rubbed together in a mortar, carbonic acid is evolved, the mass becomes blue and moist, and another double salt, the *ammoniated copper* of the pharmacopœia is formed. When a strong solution of blue vitriol is treated with water of ammonia till the insoluble sub-salt first thrown down is all dissolved, we obtain an ultra-marine blue solution, from which by gradual evaporation, cold, or the addition of alcohol, blue prisms of ammonia-sulphate of copper separate. Their formula is $CuO,SO_3, 2NH_3,HO$. They are soluble in $2\frac{1}{2}$ parts of water,

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and decompose in the air. At 300° they become apple-green, having parted with their water and one equivalent of ammonia, and at 400° one-half of the remaining alkali is expelled. Anhydrous sulphate of copper absorbs 53.97 per cent. of dry ammoniacal gas, forming a soluble blue, the constitution of which is represented by the formula $2Cu,SO_3,5NH_3$.

Sulphate of Copper and Potassa is a light blue salt, formed by crystallizing the mixed solutions of the sulphates. It is $KOSO_3Cu,SO_3,6HO$. It loses two equivalents of water at 212°, and deposits a green basic double salt on cooling. The double sulphate with soda is formed in the same manner from the blue vitriol and bi-sulphate of soda. A salt composed of the sulphates of copper, soda and magnesia, may be formed by mixture and crystallization.

Hyposulphate of Copper. $CuOS_2O_3,4HO$. When sulphate of copper is exactly decomposed by hyposulphate of baryta and the solution concentrated, rhombic prisms soluble in water are obtained, from which a small quantity of ammonia precipitates a basic hyposulphate, and with which an excess of the same reagent forms a double salt which crystallizes in azure square tables, difficult of solution, permanent in the air, and composed of $CuOS_2O_5,2NH_3$.

Phosphate of Copper. Phosphate of soda throws down from a solution of cupreous salt, this compound as a greenish powder, insoluble in water, soluble in acids, becoming brown by heat. A number of basic phosphates have been found native.

The phosphate and hypophosphate of copper possess no particular interest.

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Nitrate of Copper. When nitric acid is poured upon metallic copper, violent action takes place, even in the cold—strong effervescence ensues, heat is evolved, copious, dense, red fumes rise, and a blue solution is obtained. The reaction will be understood by a glance at the formula. Thus, $3Cu+4NO_5=3CuONO_5+NO_2$. The deutoxide of nitrogen, as it rises through the atmosphere, absorbs oxygen, and forms the red fumes of nitrous acid. To obtain the solution, the use of concentrated nitric acid must be avoided, or a green insoluble basic salt will subside.

The crystals, obtained from this solution at low temperatures, contain six equivalents of water; those procured at high temperatures, only three. They are fine blue prisms, those containing six equivalents of water being paler than those which have only three. They deflagrate on red hot coals and behave generally like other nitrates. They oxidate some metals very powerfully. Powdered, moistened with a very small quantity of water, and wrapped in tin foil, spontaneous ignition takes place.

Anhydrous nitrate of copper has been obtained. When the crystals are heated, they lose water and nitric acid, and are converted into a sparingly soluble basic nitrate, of the formula $4CuO,NO_5$. If the heat is pushed, all the acid is driven off and oxide of copper left.

With a small quantity of ammonia the basic salt is precipitated, and with a larger proportion it is dissolved, forming a blue solution, which deposits crystals of the constitution, $CuONO_5,2NH_3$. By passing ammoniacal gas into a concentrated solution of nitrate of copper, and carefully evaporating, a compound of amide of cop-

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per with nitrate of ammonia ($CuNH_2,NH_4ONO_5$) is formed.

CARBONATES OF COPPER.

The native carbonates will be described in the next chapter. Of the artificial carbonates, the best known is the

Bibasic Carbonate of Copper, $2CuOCO_2,HO$. It is obtained by treating a copper solution with an alkaline carbonate, as a bulky, blue, gelatinous precipitate. If this be gently heated with the supernatant liquor, it assumes a granular form and a green color, and in this condition, is sold as a pigment under the name of *mineral green*. If long boiled with the solution from which it has been precipitated, all the carbonic acid is gradually driven off, and black oxide of copper is left.

An *Ammoniacal Carbonate of Copper*, $CuO,C_4H_3O_3$, HO, has been obtained in fine blue needles, by dissolving the bibasic carbonate in ammonia, and adding alcohol.

Double *carbonates* with *potassa* and *soda* may be crystallized from a solution of the bibasic carbonate in the bicarbonate of either of the bases.

Borate of Copper is a pale green powder, slightly soluble in water, fusing to a green glass. It may be obtained by melting oxide of copper and borax together, and dissolving out the alkaline salt with water.

Silicate of Copper is green, and has been obtained artificially by fusing oxide of copper with glass.

The salts with the *halogens* are of no special interest nor importance.

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The *chlorate*, formed by direct union of the oxide with chloric acid, forms green deliquescent crystals. The *perchlorate*, formed in the same way, is in blue deliquescent crystals. Like other chlorates and perchlorates, they deflagrate with red hot charcoal. The *iodate*, obtained in the same manner, or by double decomposition, is sparingly soluble in water. The *bromate* is in sea-green crystals.

ACETATES OF COPPER.

There are several combinations of oxide of copper with acetic acid. One of these is neutral; the rest are basic.

Neutral Acetate of Copper. $CuOC_4H_3O_3,HO$. This salt is obtained by dissolving oxide of copper or verdigris in acetic acid, or by precipitating acetate of lead with an equivalent of sulphate of copper. By crystallizing any of the solutions thus obtained, the salt separates in dark-green, oblique rhombic prisms, with oblique terminal planes. It is soluble in 13.4 parts of cold and 5 of boiling water. In the air, it burns with a green flame, and when distilled in close vessels it gives off the various products of the decomposition of vinegar, and then strong acetic acid, leaving behind finely divided and easily inflammable metallic copper. Mixed with honey, sugar, &c. it is decomposed, small, red, octohedral crystals of suboxide of copper subsiding, and formic acid remaining in the liquid.

If the solution be made with dilute acid and crystallized at a low temperature, the crystals are blue four-sided prisms, containing 5 equivalents of water, 4 of which are lost when the salt is heated.

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Commercially, this salt is prepared by dissolving in a copper kettle, one part of verdigris in two of distilled vinegar, with the aid of a slight heat and constant agitation with a wooden spatula. As soon as the liquid has attained the greatest possible intensity of color, it is decanted into well glazed earthen vessels, and fresh vinegar is added to the residue. If this is not sufficient to saturate the acid, more verdigris is added. The clear solution is then evaporated to a syrupy consistence, and crystallized around sticks in a room heated with stoves. As thus obtained, the crystals are blue and rhomboidal.

Basic Acetates of Copper—Bibasic Acetate of Copper. Verdigris. The formula for this salt, as commonly written, is $CuO,C_4H_3O_3$ $CuO,HO,5HO$, which assumes it to be a compound of the blue neutral acetate with the hydrated oxide. In reality, however, it is a very variable salt, and the analysis does not always correspond with this theoretical constitution.

It is obtained by exposing sheets of metallic copper to the mash of the grape, while it is undergoing the acetous fermentation, or by wrapping them in cloths moistened with acetic acid. There is a difference in the color of the two products, that obtained by the former process being blue, while the result of the latter operation is green. It is a hard tough mass, varying in color from a blue to a green, and decomposed by cold water into two salts, presently to be described.

Tests. It should be dry, of a clear bluish green tint, soluble in ammonia and diluted acetic acid, and when ignited in a close vessel, it should leave a residue of metallic copper mixed with carbon.

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Sesquibasic Acetate of Copper. $3CuO2(C_4H_3O_3),6HO$. When verdigris is treated with warm water, it is decomposed, and a blue amorphous mass, the sesquibasic acetate remains behind, after spontaneous evaporation. Should the solution have been previously mixed with alcohol, this same salt is obtained in crystalline scales. When heated to the boiling point, a concentrated solution deposits a liver-brown powder.

Tribasic Acetate of Copper. $3CuOC_4H_3O_3,3HO$. When verdigris is exhausted of its soluble salts by digestion in water, or when a solution of the neutral acetate is digested with hydrated oxide of copper, a light green tasteless powder, the tribasic acetate, is obtained. It is the most permanent of the acetates of copper, losing no water at 212°. Boiled with water it undergoes the same decomposition as the last named salt, the neutral salt being found in the solution. Heated in the open air it burns with feeble deflagration.

Hyperbasic Acetate of Copper. The formula for this salt has been written, $48CuO,C_4H_3O_3,12HO$; but it may well be doubted if there be any definite compound of the kind. It is probably a combination of the oxide with some of the other acetates. It is deposited as a liver-brown powder when any of the other acetates is boiled with water. When dry it is black and slightly soluble in water.

Commercial Verdigris, is a variable compound of the above named acetates. The greener varieties, according to Berzelius, are principally made up of the sesquibasic acetate, while the bibasic salt is the chief component of the blue varieties.

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It is made in the south of France, by exposing copper sheets to the action of the fermenting residue of the grapes, the hulls, &c., which remain after the expression of the must. This refuse is put into earthen vessels, covered with lids and surrounded by straw mats to retain the heat. Fermentation soon begins and the temperature rises. The proper time for commencing the operation is determined by introducing a slip of copper as a test into the fermenting mash. This is allowed to remain twenty-four hours, when, if it be covered with uniform green layer concealing the whole surface of the copper, all is ready for commencing the manfacture. If, however, drops of liquid remain on the surface of the metal, the heat is considered to be insufficient and the materials are allowed to ferment another day.

Slips of copper, 6 inches long by 3 broad, and weighing about 4 ounces, having been well beaten upon an anvil, to remove all scales, consolidate the metal and give it a smooth hard surface, are now heated over a charcoal fire, and introduced into earthen vessels in alternate layers with the fermenting materials, the top and bottom strata being composed of the grape refuse. From thirty to forty pounds of copper are put into each vessel, the whole covered up with the straw mats and left at rest. In from ten to twenty days the vessels are opened and the plates examined, when, if they are covered with glossy isolated crystals, they are placed upright to drain, in a corner of the cellar, upon a wooden floor. After two or three days they are moistened by being dipped into water or spoiled wine, and

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then returned to the fermenting vats in the same order as before. This operation is performed every week for six or eight times.

In consequence of this treatment, the plates swell, and become invested with a green layer of verdigris, which is removed with a knife. In this condition, it is called *fresh* or *humid*, and five or six pounds of it (i. e. about 16 per cent.) are obtained from each vessel. It is dried by kneading it in wooden troughs and suspending it in leathern bags where it can be fully exposed to the action of the sun and air. It loses about half its weight, and becomes so hard that a knife, driven through the bag, cannot pierce the loaf of verdigris.

A purer variety is made in some parts of France and in England, by stratifying the copper sheets with layers of cloth soaked in acetic or common pyroligneous acid, in wooden boxes. The cloths are moistened with acid every three days, until small crystals make their appearance, which takes place in about twelve days. They are then, as in the last described process, moistened with water every week, the cloths removed, and a small space left between the plates for circulation of air. The operation is finished in five or six weeks.

This substance is also made by putting rolls of sheet copper in vessels containing vinegar, in the same manner as plates of lead are treated in the manufacture of white lead.

Uses. Verdigris has extensive applications in the arts. It is used as a pigment in oil painting, and as the basis of other pigments hereafter to be mentioned. It is also employed in lacquering, in bronzing copper,

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in calico printing as a resist-paste, in dyeing, especially the dyeing of hats. The *neutral acetate* is used as a green pigment. It was formerly employed in the manufacture of concentrated acetic acid. It has the same applications to dyeing and calico printing, as the common verdigris.

ARSENITES OF COPPER.

Scheele's Green. When neutral salts of arsenious acid and of copper are mixed, a fine green precipitate falls. This is largely employed as a pigment. It forms that peculiar delicate green so much used by paper stainers, and has been applied to dyeing and calico printing, by effecting the decomposition upon the fabric to be tinted.

It is made on the large scale by dissolving 3 parts of carbonate of potassa and 1 of arsenious acid in 14 parts of water, and by gradually adding this while hot to a boiling solution of 3 parts of sulphate of copper in 40 parts of water, the mixture being constantly stirred. The exact hue of green may be modified by altering the quantity of arsenious acid.

Schweinfurth Green. When boiling solutions of acetate of copper and arsenious acid are mixed, a bulky olive green precipitate is immediately produced. If this be boiled in the supernatant liquid, it changes its form and color, becoming a dense granular powder of a beautiful green tint. The same alteration takes place in the cold, if time enough be allowed for the reactions. It is said that the best result is obtained by adding to the hot mixed solution its own bulk of cold water and allowing it to stand, until the desired color is obtained, in a glass globe filled up to the neck with the mixture. The com-

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mercial formula given by Kastner, as quoted by Ure, is as follows:—For 8 parts of arsenious acid, take from 9 to 10 of verdigris; diffuse the latter through water at 120° F., and pass the pap through a sieve; then add the arsenical solution and set the mixture aside till the reaction of the ingredients shall produce the desired hue. If a yellowish tint is required, more arsenious acid must be used. By digesting Scheele's green in acetic acid, a variety of Schweinfurth green may be obtained.

This is a richer pigment than the last named. It is useless to say that they are both very deadly poisons, and the fact is only mentioned here to caution the reader against the *green candies* sold by our confectioners, many of which are colored with Scheele's green.

There is another arsenite of copper, $2CuOAsO_3$, which is precipitated by neither acids nor alkalies, and which yields a yellowish green salt on evaporation. It is made by digesting the oxide or the carbonate of copper in arsenious acid.

SULPHO-SALTS.

A *Subsulphophosphite of Copper* is formed when bisulphide of copper is treated with sulphide of phosphorus, and gently warmed in a current of hydrogen. It is a yellow powder of the composition $2Cu_2S,PS_3$. By heating this, two equivalents of sulphur are driven off, leaving $2Cu_2S,PS$.

The *hyposulphophosphite* (CuS,PS) is obtained like the last compound by using the sulphide of copper instead of the bisulphide. Various salts are formed from it by decomposing it through the agency of heat.

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CHAPTER II.

ORES OF COPPER.

THE minerals into which copper enters as an essential ingredient are both numerous and important, but lie, for the most part, out of the range of a book like this. The working ores, as they are termed by smelters, may be reduced to certain classes possessing distinct outlines.

Native copper, though not an ore of copper in the strict mineralogical sense of the word ore, has, nevertheless, a place in the smelter's classification and constitutes a class by itself. The *second* class comprises the *native oxides* and *chlorides* of copper. The *third* class is occupied by the combinations of copper with *sulphur*, *selenium*, *arsenic* and *antimony*. The *silicates* form the *fourth* class, and the *fifth* class is taken up with the remaining oxysalts of this metal.

CLASS I.

Native Copper may exist either crystallized, amorphous or in various imitative forms. When crystallized, it belongs to the monometric, tesseral or cubic system of crytallographers; that is to say, whatever may be the form of any given crystal, it is in every case a modification of a cube, and can be referred to that figure. The forms commonly enumerated are the cube, the octahe-

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dron, the rhombic dodecahedron, the twenty-four hedron and the four×six hedron, or cube replaced on every side by a four-sided pyramid. I have also seen obscure pentagonal dodecahedral crystals and every possible modification and combination of these various forms. Very often the matrix in which it is contained impresses its own crystalline form upon the copper, so that the metal is covered with indentations faithfully copying the projections of the crystals among which it lies embedded. As this occurs sometimes in masses which are covered with the proper crystals of copper, it constitutes quite a puzzling phenomenon to the beginner in crystallography.

One of the most common, and at the same time most beautiful forms of this metal, is that in which it is diffused through the rock in a branching, arborescent form, so that it resembles a great metallic lichen. Often it will be found presenting this irregular plant-like form on one side, while on the other it is covered with fine crystals of the forms already described. It is also found in great masses, in thin films, and in broad sheets.

It is soft enough to be cut with a knife, its hardness varying according to the commonly received standard, from 2.5 to 3. Its specific gravity, when pure, is 8.74. It possesses the color and lustre of fused copper,* and like it is ductile and malleable.

Its behavior with chemical reagents is of course identical with that of metallic copper, however obtained. Before the blow-pipe it fuses, becoming covered with a coating of black oxide. It dissolves rapidly in nitric acid, with effervescence and the escape of red fumes,

* It occasionally presents the various tarnishes already described as occurring upon ingots.

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and gives a blue solution with ammonia. By these properties together with its malleability, it is easily distinguished from all other substances.

Native copper is very extensively distributed over the earth's surface, being a common mineral in most copper mines. Very fine crystals are obtained from the Faroe isles and from Siberia. Cornwall contains considerable quantities of it, and the South American mines also furnish it. It is found abundantly in the United States. In New Jersey it is quite common, especially at Schuyler's mine, Flemington, Brunswick and Somerville. Near the last named place, a mass was found weighing 78 pounds, which is said originally to have weighed 128 pounds. Near New Haven, Connecticut, a mass was found weighing 90 pounds. There is much native copper in Virginia, along the Blue Ridge, where it is commonly found in broad sheets of variable thickness, coating epidotic trap and filling up the seams in that rock. At Manassa's Gap, in Fauquier county, it is diffused through the trap, in combination with the two oxides and silicate of copper. Its greatest masses, however, occur upon the shores of Lake Superior.

The Lake Superior copper contains also native silver, generally occurring in cavities of the copper. It is also said to be alloyed with silver to the extent of 0.3 per cent.; but I have repeatedly analyzed specimens of this copper, and only in a few instances have I discovered the more valuable metal. Specimens there are undoubtedly which contain much more than that amount, but the majority have only a trace of silver, and in many fragments none at all can be detected. Hautefeuille has recently detected mercury in this copper.

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CLASS II.

Red Copper may be massive, granular, earthy, or crystallized. Its crystals belong to the same system as native copper. When pure, it is usually of a fine cochineal red color, though it is occasionally crimson, especially by transmitted light. Sometimes, however, the opaque crystals have an iron-gray tint upon the surface, resulting probably from oxydation; but even in this case, the red color shows itself when the crystal is pulverized. The finest specimens are transparent, and have a rich ruby hue.

When massive, it is usually found in connection with native copper and the black oxide. It occurs mingled with metallic copper and the black oxide, above and between the bricks of a refining furnace. Many beautiful specimens may be obtained from such spots, the clear ruby red of this compound contrasting finely with the rich steel gray of the fused black oxide. *Tile ore* is an earthy variety, usually brownish or dark brick red. It is mixed with a variable amount of red oxide of iron. In Cornwall, and at Rheinbreitenbach, on the Rhine, it is found in capillary crystallizations, to which the name *chalchotrichite* has been given.

This oxide is found in many mines, the finest crystals being obtained from Chessy, Moldawa, and Ekatherinenburg. Cornwall, especially at Huel Garland mine, near Redruth, furnishes octahedral crystals. In this country, it has been found, in the New Jersey mines, in the Tennessee and Virginia mines, and at Manassa's Gap, in Virginia.

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The composition of this ore, according to an analysis of Chenevix, is:

Copper, - - -	88.78
Oxygen, - - -	11.22

Its formula is Cu_2O, and its specific gravity 5.992.

Before the blowpipe, in the reducing flame on charcoal, it affords a globule of copper. It dissolves in hot muriatic acid, *excluded from the air*, forming a colorless solution, which gradually becomes green when exposed to the atmosphere. In nitric acid it dissolves with effervescence, forming a blue solution. From its hydrochloric solution, water throws down a white, and potash a yellow precipitate.

Black Oxide of Copper is commonly found in powder or friable masses, of an earthy appearance, mixed with sulphurets, arseniarets, &c., resulting from atmospheric action upon the other ores of the vein. It is occasionally found massive, containing crystals of cubic or allied forms. Its lustre may be submetallic and earthy, or metallic and bright. Beautiful steel gray specimens may be obtained from the hearth of an old refining furnace.

Tenorite is a variety found in the lava of Vesuvius, in small scales, hexagonal or triangular in form, of a dark steel-gray hue by reflected, and brown by transmitted light.

The black oxide is found coating many different ores, and is a product of most mines. In Polk county, Tennessee, however, it exists in great quantities, beds of it, from 25 to 90 feet in thickness, being worked there. At Keweenaw Point, Lake Superior, the compact variety has been found, and at Manassa's Gap, in Virginia,

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it occurs massive, mixed with native copper, red oxide, and chrysocolla,

Its composition is:

Copper, - - -	79.86
Oxygen, - - -	20.13

Its formula is CuO, or Cu. Its specific gravity varies, of course, with its state of aggregation. That of Keweenaw Point, is stated, by Dana, on the authority of a private communication from Teschemacher and Hayes, to be 5.140 for the crystals, and 5.386 for the compact portions.

It dissolves with a green color in muriatic acid, and without effervescence in nitric acid. Its blowpipe reactions are the same as those of the last variety.

Atacamite is a beautiful emerald, or blackish green mineral, found in Chili and Bolivia. Its system of crystallization is trimetric, and it usually occurs in rectangular prisms or rectangular octahedra. It is also found massive.

It was originally found, in the state of sand, in the desert of Atacama, between Chili and Peru, whence its name. It also occurs at Los Remolinos, in Chili, at Cobija, in Bolivia, and coating the lavas of Vesuvius and Etna.

Its composition varies according to different observers. We give two per centage statements:

Chloride of Copper, -	31.48	27.94
Oxide of Copper, -	55.94	49.57
Water, - -	12.58	22.49
	100.00	100.00

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Its formula, therefore, is $CuCl+3CuO+3HO$, or $CuCl+3CuO+6HO$.

It tinges the blowpipe flame green or blue, and gives off fumes of hydrochloric acid; and, on charcoal, yields a bead of metallic copper. It is soluble in acids.

CLASS III.

Copper Glance, or Vitreous Copper, called also Sulphuret of Copper, is of an iron gray or blackish lead-gray color, often tarnished with blue or green, and sometimes iridescent. Its crystals belong to the trimetric system. The primitive form is a six-sided prism, but it is commonly found in hexagonal tables. It is more frequently met with massive. It is very soft and friable, may be readily cut with a knife, and when scratched, gives a shining streak the color of the ore. It is very fusible, melting in the flame of an ordinary candle.

Fine crystals of this species are found in Cornwall, especially in the neighborhood of Redruth, whence one of its names, Redruthite. It occurs massive, in numerous localities, both in Europe and the United States. Crystals, of fine size and great brilliancy, have been found at the Bristol mine, in Connecticut.

The composition of this mineral, when pure, is:

Copper, - - -	79.8
Sulphur, - - -	20.2
	100

Usually, however, it is contaminated with iron, which

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makes it harder and more infusible. Thompson's analysis of a Cornish specimen is as follows:

Copper, - - -	77.16
Sulphur, - - -	20.62
Iron, - - -	1.15
	98.93

It is, therefore, a sulphuret of copper, its formula being CuS. Its specific gravity varies from 5.5 to 5.8.

Before the blowpipe, in the outer flame, "it melts, gives off fumes of sulphur, and emits glowing drops with a noise, coloring the flame at the same time blue. In the inner flame, it becomes covered with a coating, and does not melt." The blue tinge of the flame is especially observed, if the specimen has previously been moistened with hydrochloric acid. On charcoal, it gives off fumes of sulphurous acid, and leaves a bead of copper. In nitric acid it dissolves to a green solution, flocculi of sulphur floating through the liquid.

Harrisite. This has been described by Prof. C. H. Shepard as a new mineral species. It is regarded by Genth as a pseudomorph of copper-glace after galena. It occurs at the Canton mine, Cherokee county, Georgia, in forms closely resembling those of galena. My specimens are of a dark iron-gray, with perfect cubical cleavage down to the smallest fragment. Some of them have the foliated character of which Dr. Genth speaks, and most of them are curved as though they had been bent after they had been deposited.

The following are the results of two determinations by Dr. Genth:

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		I.	II.
Sulphur,	-	20.648	20.647
Selenium,		not determined	0.047
Silver,	-	0.207	0.164
Copper,	-	77.298*	77.758
Lead,	-	0.056	0.060
Iron,	-	0.442	0.359
Insoluble,	-	0.272	0.667
		98.923	99.702

Sp. gr. 5.485. H. 3 to 3.5.

Digenite is an allied mineral, found in Chili, and at Saugenhausen, in Thuringia. Its specific gravity is 4.6. It is supposed to be a mixture of copper glance and covelline.

Berzelianite is a selenide of copper, occurring in thin dendritic crusts, of a silver-white color and a metallic lustre. It is found in Sweden and the Hartz mountains, and is of no value as an ore.

Covelline, or Indigo Copper, is found in crystals belonging to the hexagonal system, and also massive or spheroidal, with a crystalline surface. Its color is indigo blue, its lustre resinous, its streak lead-gray and shining. Before the blowpipe it burns with a blue flame before becoming red hot, and fuses to a globule, which is strongly agitated and emits sparks, finally yielding a button of copper. Its composition is Copper 66.5, Sulphur 33.5.

Cantonite. A pseudomorph of Covelline has been described under this title by N. A. Pratt, Jr. He says

* Some accidentally lost.

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it is found finely crystallized in well-formed cubes, of submetallic lustre and blue-black color, and gives its specific gravity as 4.18, and its hardness as 1.5 to 2. His analysis (No. I.) may be compared with Dr. Genth's (No. II.)

		I.	II.
Sulphur,	-	33.490	32.765
Copper,	-	66.205	65.604
Selenium,	-		trace
Silver,	-		0.355
Lead,	-	.305	0.107
Iron,	-		0.251
Insoluble,	-		0.157
		100.00	99.239

Genth calls it a pseudomorph of Covelline, after Galena.

Erubescite, Phillipsite, Variegated Copper, or Purple Copper, belongs to the monometric system of crystallization. Its crystals are ill-defined, and usually cubes or octahedra. Most frequently it occurs granular or compact. Its lustre is metallic, its color, in fresh fractures, reddish-brown, something between copper and pinchbeck, and it is commonly tarnished with different hues of blue, purple, and red. It is brittle, and breaks with an uneven, small conchoidal fracture.

It is an important ore of copper, being found in Cornwall, Killarney, Tuscany, Mansfield, Norway, Silesia, Siberia, and the Bannat. It also occurs in Pennsylvania, Massachusetts, Connecticut, and New Jersey, and in most of the mining districts of South America.

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Its composition is:

	Berzelius.	Rammelsberg.
Copper, - -	62.5	55.5
Iron, - -	13.8	16.4
Sulphur, - -	33.7	28.1
	100.0	100.0

Analysis of different specimens differ still more widely than these two statements, the copper ranging from 71 to 56 per cent. This may be accounted for by supposing it to be variously mixed with other ores of copper. The only two analyses of *crystals* approach much nearer Rammelsberg's than Berzelius' table. Its formula, according to Berzelius, is $2Cu_2S+FeS$, and according to Rammelsberg, $3Cu_2S+Fi_2S_3$.

Before the blowpipe it blackens and becomes red on cooling, or if sufficiently heated, fuses to a black globule, which is attracted by the magnet.

Barnhardite is a new mineral, described by Dr. Genth, of Philadelphia. It occurs in compact masses. Specific gravity, 4.521; lustre metallic, but somewhat dull; color bronze-yellow; streak grayish black and slightly shining; opaque; fracture conchoidal, uneven; tarnishes very soon—more readily in presence of moisture, assuming a peculiar brownish, sometimes pinchbeck-brown; sometimes, also, rose-red and purple color.

Before the blowpipe, gives off sulphurous acid, and fuses easily to an iron-black magnetic globule; and with borax, it gives the relations of copper and iron; with carbonate of soda and borax, metallic copper. The calculated composition is as follows:

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Copper,	-	-	-	48.14
Iron,	-	-	-	21.33
Sulphur,	-	-	-	30.53

The formula is $2Cu_2S+Fe_2S_3$.

"I have found this mineral associated with other copper ores at Dan. Barnhardt's land, (hence its name,) and Pioneer Mills, Cabarrus county; Dr. O. Dieffenbach observed it in the Phœnix and Vanderburg mines of the same county, and I saw it also amongst copper ores from the neighborhood of Charlotte, Mecklenberg county, N. C. It seems to be abundant in North Carolina, and is, of course, a very valuable copper ore."*

Copper Pyrites is a yellow ore, with a brilliant metallic lustre, and is often mistaken by the inexperienced for native gold. It usually occurs massive, having an irregular and slightly conchoidal fracture. It is also found botryoidal, globular, stalactitic, and crystallized. Its crystals are octahedral or tetrahedral, and belong to the dimetric system. It is liable to tarnish, and is sometimes iridescent. Its streak is greenish black and shining, and its powder is a fine bronze green.

This is the most abundant of all the ores of copper. It is the principal product of the Cornish mines, which yielded, in 1853, 180,000 tons of ore. It is also worked in Scotland, Sweden, Germany, Hungary, Australia. In the United States, it is a very frequent accompaniment of galena, and is also found alone in numerous places. It is worked in several of the States, but its localities will be described in the chapter on Mines.

* American Journal of Science and Art, January, 1855, p. 18.

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Its composition is:—

Copper - - -	34.47
Iron - - -	30.48
Sulphur - - -	35.05
	100.00

Its formula is $Cu_2S+Fe_2S_3$. Its specific gravity varies from 4.1 to 4.3.

Before the blowpipe, at a low heat it blackens, but becomes red on cooling, in consequence of the oxidation of its iron. At a higher heat, it fuses to a black, brittle globule, which is attracted by the magnet, and if the heat be kept up long enough, upon charcoal, it yields a metallic globule. Fused with a small quantity of borax, it also furnishes a bead of pure copper. Nitric acid forms with it a green solution, having sulphur in the liquid.

This ore need not be mistaken for anything else. It is easily distinguished from gold by the fact that it is not malleable. From iron pyrites it may be distinguished by its color, which is a rich golden yellow, while that is a pale brass-color, and also by its softness, iron pyrites being hard enough to strike fire with steel. It is, however, often intermixed with this other mineral, and then it is both paler and harder than the pure variety. The action of nitric acid is also characteristic.

The copper pyrites of commerce is a very variable ore, and it is not always easy for the most experienced to determine its value by simple inspection. It is commonly largely mixed with silicate of copper, malachite, iron pyrites and quartz, and some of the poorest ores,

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when pounded up and dressed, can hardly be distinguished from the best. There is a very deceptive ore of this kind in Louisa county, Virginia. It is essentially an iron-pyrites with sufficient copper diffused through it, to give it the black tarnish common on the rich Cuba ores, and yet samples of it, when dressed and sent to market, though looking very well, have furnished only between from one and two per cent. of copper. *

Domeykite, or arsenical copper is a tin-white, slightly yellowish mineral, often presenting an iridescent tarnish, occurring in reniform and botryoidal masses, as well as massive and disseminated. It is found in Chili and in Cornwall. It is composed of arsenic 28.3, copper 71.7. Before the blowpipe it fuses, giving off the garlicky color of arsenic.

Condurrite, a mixture of domeykite, with red copper ore and arsenite and sulphuret of copper, is greenish-black or blue in color, and soft in texture.

Gray copper, fahlerz of the Germans, usually occurs massive, but is also found in cubes and tetrahedra, belonging to the monometric system. Its color varies from steel-gray to iron-black, and its streak is the same color or slightly brownish. It is brittle and has a conchoidal fracture.

In composition it is a very variable mineral, as the following table will show :—

* Breithaupt describes a variety of this pyrites under the name of Cuban, occurring in cubes or massive. Its color is between bronze and brass-yellow, its streak black, its hardness 4; its specific gravity, 4.026. It contains 19 per cent. of copper, fuses easily before the blowpipe, giving off fumes of sulphur but no arsenic. His specimens came from the Island of Cuba. I have seen it occasionally in cargos of ore from the West coast of South America.

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	Sulphur.	Antimony.	Arsenic.	Copper.	Iron.	Zinc.	Silver.	Gold.	Quartz.	
From Clausthal,	24.73	28.34	"	34.48	2.27	5.55	4.97	"	"	Rose.
" Wolfach,	23.52	26.63	"	25.33	3.72	3.10	17.71	"	"	Rose.
" Corbiers,	25.30	25.00	1.50	34.30	1.70	6.30	0.70	"	"	Berthier.
" Gersdorf,	26.33	16.52	7.21	38.63	4.89	2.76	2 37	"	"	Rose.
" Unknown,	10.00	"	14.00	48.00	25.50	"	0.50	"	"	Klaproth.
" Cabarrus Co. N.C.	25.48	17.76	11.55	30.73	1.42	2.53	10.53	"	"	Genth.
" Buckingham Co. Va.	28.46	5.10	16.99	40.64	4.24	3.39	0.42	*Trace*	1.24	Taylor.

From this table, it would appear impossible to construct anything like a formula for this mineral. It is usually said to be $4(Ag,Cu_2ZnFe)S$ and $(As,Sb)S_3$, —but it is manifest that neither this nor any other can apply. Dr. Genth considers his specimen from Cabarrus county a new species, and offers for it the formula $5(Ag,Cu_2,Zn,Fe)S \times 2(As,Sb)S_3$. Rose thinks that the general composition of the mineral may be represented by the formula $Fe_4Cu_{16}Sb_6S_{21}$, in which each of the different metallic substances may be, to a greater or less extent, replaced by others, so that sulphuret of antimony may be substituted by sulphuret of arsenic, and sulphuret of copper by sulphuret of silver.

The blowpipe reactions must necessarily vary somewhat. They usually, however, consist in the evolution of fumes of antimony and arsenic, the former recognized by its white smoke, and the latter by its garlicky odor. With this is combined the odor of sulphuric acid from the sulphur present. The coal will be covered with the white incrustation of antimony, or if zinc be present by a yellow sublimate, becoming snow-white on cooling. When finely powdered, it dissolves in nitric acid, leaving a slight residue, and forming a brownish-green solution.

Dr. Genth gives the following as the re-actions of his Cabarrus county ore. "Before the blowpipe, decrepitates slightly; in an open tube disengages sulphurous

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acid, gives a sublimate of arsenious acid; on charcoal it emits fumes of an alliaceous odor and covers it with white incrustations; it fuses into a magnetic globule and gives with fluxes the re-actions of copper and iron."

This is a very important ore of copper, and is additionally valuable from the silver it contains. It occurs in fine crystals near Cornwall, near St. Austell, though their surface is commonly rough and dull. More brilliant crystallizations are found at St. Andreasberg in the Hartz; Kremnitz, in Hungary; Freyberg, in Saxony; Dillenberg, in Warsaw; and Kapnik, in Transylvania. It is found massive in the Tyrol, and in Siberia. In the United States, according to Dr. Genth who first discovered it in this country, it occurs in Cabarrus county, North Carolina; at Eldridge's gold mine in Buckingham county, Virginia; and in Duchess county, New York.

Tennantite has a close resemblance to gray copper, and occurs in brilliant crystals investing other ores of of copper. It is found in Cornwall and Norway.

Wolfsbergite, or antimonial copper, is a sulphantimoniate of copper, occurring in small aggregated tabular prisms, in quartz, at Wolfsberg in the Hartz.

Bournonite is a gray or blackish mineral, crystallizing in prisms, belonging to the trimetric system. Its lustre is metallic, its fracture conchoidal and uneven.

Rose's analysis of a specimen from Pfaffenberg, is:—

Copper, - - -	12.65
Lead - - -	40.84
Antimony - - -	26.28
Sulphur - - -	20.31
	100.08

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Before the blowpipe, it fuses to a black globule, and gives off fumes of antimony. At a high heat the charcoal is coated with a yellow deposit of oxide of lead. It dissolves easily in nitric acid, forming a blue solution.

It is found in several of the European mines, but has not yet been discovered in this country.

CLASS IV.

Dioptase is a rare and beautiful emerald green, transparent or translucent mineral, occurring in rhombohedral crystals, in quartz, at Altyn Tübé, in Siberia. Its lustre is various, its streak green, and its fracture conchoidal and uneven. It is a silicate of copper, containing 3 equivalents of oxide of copper, 2 of silicic acid, and 3 of water.

Chrysocolla is a silicate of copper, occurring usually as an incrustation, but sometimes disseminated through quartz. It has various tints of blue and green, from a turquoise color to a bright mountain-green. It is sometimes brown from admixture of foreign ingredients, especially iron. The translucent varieties are hard and brittle, the opaque ores soft and earthy. It is often mixed with other ores, especially with the carbonates of copper.

It is a very common ore of copper, and attends almost every deposit of that metal which has a silicious veinstone. It is in primitive regions, especially in granite, a frequent surface indication, being often diffused through the quartz rocks, so as to give them a decided green stain. At Manassa's Gap, it envelops the native copper and the oxides of copper which are diffused through the quartz.

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Its composition is :—

Silica - - -	34.82
Oxide of copper - -	44.83
Water - - -	20.35

Its formula is $3CuO,2SiO_3+6HO$. Its specific gravity is from 2 to 2.238. Before the blowpipe, on charcoal, it blackens in the inner flame but does not melt. With borax, it fuses to a green glassy globule, containing some specks of metallic copper.

CLASS V.

Azurite occurs in beautiful azure blue crystals, belonging to the monoclinic or rhomboidal system. These are transparent or subtranslucent, having a glassy or adamantine lustre, and a conchoidal fracture. The streak is a lighter blue. It also is found in mamillary concretions, and in dull earthy masses.

The finest crystals come from Chessy, near Lyons; though excellent specimens are found in the Bannat, in Siberia, and in Cornwall. In this country it is found at Perkiomen, near Philadelphia, and at other places in Pennsylvania. It is also to be obtained near Sing Sing, in New York, and near New Brunswick, in New Jersey.

Its composition is

Oxide of copper - -	69.09
Carbonic acid - -	25.69
Water - - -	5.22
	100.00

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Its formula is $2CuO,CO_2+CuO,HO$; its specific gravity 3.5 to 3.831. Before the blowpipe, in the oxidating flame, it is reduced to a black globule. In the reducing flame in the loop, it burns with a green flame, and on charcoal is reduced to metal. Heated in a glass tube, it gives off water and becomes black. Fused with borax, it forms a green glass. It dissolves in ammonia and the acids, effervescing with the latter.

It has been ground to a powder and used for paint, but is liable to turn green.

Malachite is a mineral of various shades of green, mostly emerald. It is found in crystals belonging to the monoclinic system, but more commonly occurs in botryoidal masses, which are often radiated, and sometimes made up of minute crystals. Occasionally they seem to have been formed in successive layers, the boundaries of which are distinctly seen on breaking the mass. I have some specimens from Patapsco mine, in Carrol county, Maryland, which form beautiful green fibrous cones, an inch or more in height, imbedded in a soft, red, ferruginous mass. It is also found in a friable and pulverulent state, when it is commonly mixed with various earthy impurities.

It is met with in great masses in Siberia, and it has been wrought into table-tops, &c. The Emperor of Russia, some years since, presented the King of Prussia with a pair of beautiful vases, of great size, made of this material. It is valuable not only as an ore of copper, but also as a precious stone, being wrought by the lapidary into numerous articles of jewelry. It is a very convenient form for the manufacture of blue vitriol, and

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is also ground into a paint for the use of artists. In smaller quantities, it is an accompaniment of almost every ore of copper.

It composition is

Oxide of copper - -	71.82
Carbonic acid - -	20.00
Water - - -	8.18
	100.00

Its formula is $2CuO,CO_2+HO$. Its reactions are the same as those of azurite. Its specific gravity is from 3.7 to 4.008. It is often mixed with lime, zinc, and other substances, and these mixtures have occasionally been described as distinct minerals.

Blue vitriol has already been sufficiently described in the previous chapter. It is found at most mines of the sulphurets of copper, as a consequence of the oxidation of these ores, and the subsequent solution and crystallization of the resulting salt of copper. It is of course impure from the presence of iron. At some mines, the blue water running from the ore is collected in cisterns, into which scrap-iron is thrown. This precipitates the copper which is slowly oxidated, so that a mixture of red oxide and metallic copper is the result, a compound easily and cheaply reduced to the metallic state.

Brochantite is a mixture of sulphate of copper and the hydrated oxide, in the proportion of one of the former to three of the latter. Its lustre is vitreous, its color emerald-green or blackish-green, its streak is paler. It occurs in transparent crystals, belonging to the trimetric system, also in masses and botryoidal concretions.

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Lettsomite is a velvety blue coating on an earthy hydrated oxide of iron, occurring sparingly at Moldawa in the Bannat. It is a mixture of the sulphates of copper and alumina, the oxide of copper and water.

Connellite is a blue, translucent mineral, with a vitreous lustre, occurring in hexagonal prisms in Cornwall. It is a mixture of the sulphate and the chloride of copper.

Thrombolite is an amorphous, green, opaque phosphate of copper, with a vitreous lustre, found at Retzbanya, in Hungary.

Before the blowpipe, it colors the flame first blue and then green. On charcoal it fuses easily to a black globule, and then yields a bead of copper.

Phosphorochalcite is a dark green, translucent phosphate of copper, found at Rheinbreitenbach, Nischne Tagilsk and Hirschberg.

Libethenite is an olive-green, subtranslucent phosphate of copper, having a resinous lustre and a subconchoidal fracture. It belongs to the trimetric system of crystallization. It is found in Hungary, Cornwall and the Ural Mountains.

Olivenite is a phosphate and arseniate of copper, of a dark green or brown color, crystallizing in forms belonging to the trimetric system, and also occurring in globular, reniform and fibrous concretions.

Euchroite is a bright emerald or leek-green mineral, found at Libethen, in Hungary, in large crystals. It contains 33 per cent. of arsenic acid, and 54 of oxide of copper.

Tyrolite is a pale green mineral, composed of arse-

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niate of copper, carbonate of lime and water. It occurs in the cavities of calamine, calc-spar or quartz, accompanied by other ores of copper, appearing in small aggregated and diverging fibrous groups, possessing a delicate silky lustre.

Erinite occurs in mamillated, crystalline, roughened coatings, made up of several layers often easily separable. Its color is a fine emerald-green, inclining to grass-green, its streak paler. It contains 33.78 per cent. of arsenic acid, 59.44 of oxide of copper, 5.01 of water, and 1.77 of alumina. It is found in the county of Limerick, in Ireland.

Aphanesite is of a dark green color, inclining to blue, and sometimes to dark blue. Its crystals are brilliant, but small, and belong to the monoclinic system. It is found in Cornwall and in the Erzgebrige, and contains 30 per cent. of arsenic acid and 54 of oxide of copper.

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CHAPTER III.

ANALYSIS OF COPPER ORES.

In the first chapter we have given an account of the reactions of pure copper. It is only necessary to bear these in mind, to be able to recognize this metal. Still, as there are some precautions to be observed in getting the solutions to be operated upon, it may be well to give here a brief account of the method of proceeding in the qualitative examination of a mineral supposed to contain copper, before undertaking to describe the quantitative analysis of such ores.

This will vary very much with the nature of the metals which may happen to be combined with the copper. If, for example, the presence of lead be suspected, the ore must be treated with dilute nitric acid. It is best to take a mixture of one part of acid with five or six of water, and allow it to stand on the ore at a gentle heat, until the flakes of sulphur which have separated are of a clear yellow color. Should there be any other insoluble matter left, the solution must be poured off, the residue well washed, and then treated with boiling concentrated nitric acid, until nothing is left undissolved but the vein-stone and the floating sulphur. The two solutions are now mixed, and to them is added a little sulphuric acid. A white precipitate immediately falls, which is indicative of the presence of lead.

It must, however, be borne in mind that lime also

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produces a white precipitate with sulphuric acid, and the tyro may be easily deceived. He will, therefore, remark that the lead salt is the heavier of the two, that it dissolves readily in boiling muriatic acid, and that the solution on cooling, deposits crystals. A more decided distinction is the action of sulphureted hydrogen or sulphide of ammonium. The white precipitate must be thoroughly washed upon a filter, and then subjected to a stream of sulphureted hydrogen gas, or moistened with a solution of sulphide of ammonium. A dark brownish black color is produced if the salt be one of lead, whereas, sulphate of lime, when pure, is unaffected by either of these tests. Thorough washing is essential, because other metals, soluble in nitric acid, are blackened by these reagents.

If the copper ore, under examination, should be supposed to contain silver, that question is determined by dissolving the ore in nitric acid, filtering, and to the clear solution adding muriatic acid or a solution of salt. Immediately a white curdy precipitate falls, or if the quantity of silver be small, a milkiness shows itself in the liquid. This precipitate also needs to be closely scanned, for lead is precipitated by hydrochloric acid. The lead salt, however, is heavier, subsides more rapidly, and is crystalline in its texture. It may also be dissolved in a large quantity of hot water, and crystallizes out of this solution on cooling. The silver salt, on the other hand, is curdy, subsides slowly, and is not soluble in hot water. It turns purple or dove-color on exposure to light, and dissolves readily in ammonia, whereas the lead salt is insoluble in that reagent, and is not affected by light.

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Should the two metals co-exist, they will both be precipitated, and must be separated in the dry way, by cupellation, hereafter to be described.

The presence of gold is detected, by dissolving the ore in aqua-regia, (nitro muriatic acid,) and adding a solution of sulphate of iron, when the precious metal falls in a blackish brown powder. Some precautions are necessary in this process to insure success. The solution must be carefully evaporated to dryness over the water bath, and then moistened with hydrochloric acid. This process must be repeated several times, until no more fumes of nitrous acid are given off, and the solution must be diluted.

The most common way of detecting the presence of copper in a mineral is to dissolve the ore in boiling aqua-regia, filter and add to the filtrate a solution of ammonia. Iron, if present, falls as a greenish or red-brown mud, and the supernatant liquor has a very fine blue color. Here too it is necessary to guard against mistakes. Nickel also gives a blue solution with ammonia. The experienced eye, however, can hardly be deceived, for the solution of nickle is a pale sapphire blue, while that of copper is a deep ultramarine. Even in diluted solutions, this difference is observed.

The test with polished iron is not liable to these objections. Even in very dilute solutions of copper, a knife blade or a piece of clean wire is so completely coated, that it appears to be converted into copper. One part of copper in 180,000 of solution can be distinctly recognized in this manner.

In some rare cases, nitro-muriatic acid will not dis-

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solve the powdered mineral containing copper. It is then necessary first to fuse the mineral with carbonate of soda, and then to subject it to the action of the acid and proceed as before.

The blowpipe methods have been described in the last chapter.

A common way of determining the presence of copper in an ore is to mix it with carbonate of soda, pearlash or other alkaline flux, intimately mixed with finely powdered charcoal, and to heat it nearly to whiteness in a crucible, by the fire of a smith's forge. After keeping it at this heat for some ten or fifteen minutes, or until the contents of the crucible are in quiet fusion, it is taken off, allowed to cool, and when the crucible is broken, a button of copper, enveloped in a gray, shining coating is usually found below the flux.

It can hardly be necessary to say that in all these processes it is necessary that the ore should be reduced to the finest possible powder, before it is subjected to the operations recommended.

If it be designed to make a systematic investigation of all the contents of a copper ore, the following methods should be resorted to.

The ore must first be heated gently with dilute nitric acid, as before described. It is then, after everything soluble in the dilute acid has been taken up, to be boiled with concentrated nitric acid, until the separated sulphur, if there be any present, has assumed a clear yellow color. These two solutions are poured off from the insoluble residue, and mixed together and filtered. We will call this solution No. I. Should the residue be

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white, and it be desired to determine the presence of the earths, it must be boiled with hydrochloric acid. Should it be colored, first hydrochloric, and then nitric acid is to be added and the boiling continued. The whole is then evaporated to dryness over a water-bath,* moistened with hydrochloric acid and drenched with distilled water. It is now filtered from the insoluble residue, and constitutes solution No. II. Should the residue still be colored, it is to be washed thoroughly with hot water, and treated as we shall presently describe.

To the solution No. I. hydrochloric acid is added. Should a white precipitate, which does not dissolve or diminish on the further addition of acid, be thrown down, it indicates the presence of lead, mercury or silver, or all three. It must be well washed with cold water, and then heated with a large quantity of water. If sulphuric acid throws down a heavy white precipitate from this hot solution, the presence of *lead* is established. Should a portion remain undissolved, it is to be heated gently with excess of ammonia. The blackening of the precipitate indicates *mercury*. The ammoniacal solution is decanted from the residue, if there be any, and mixed with dilute nitric acid until a piece of litmus paper, dipped into it becomes red. If there should fall a white curdy precipitate, becoming purple by exposure to light and dissolving in ammonia, *silver* is present.

The liquid filtered from the first precipitate is added to No. II, and a stream of sulphureted hydrogen gas is

* This can easily be made extemporaneously by placing an evaporating dish, or even a common saucer, over a tin cup containing water, which is to be kept boiling.

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passed through the mixed solutions. This is obtained by adding dilute sulphuric acid to sulphuret of iron;* the operation being conducted in a bottle fitted with a cork and a bent glass tube which conveys the gas into the solution. A black precipitate immediately falls, and the gas is passed through till nothing more is thrown down, and the liquid smells strongly of it. The whole is then to be subjected to rapid filtration, taking care that during the whole process the liquid is charged with sulphureted hydrogen, which may be known by the smell.† The filtrate we shall call solution No. III.

The sulphides likely to be found in the precipitate, are those of antimony, arsenic, bismuth, cadmium, copper and gold. The latter must be sought in the original solution as already described. The precipitate being well washed, is put into a small flask and boiled with *yellow* sulphide of ammonium,‡ when the first two sul-

* This re-agent is easily obtained by heating a bar of iron to bright redness and holding against it a roll of brimstone. Sparks are emitted and globules fall, which are caught in a pail of water. These are found to be partly yellow and partly gray. The latter are selected. A better way of preparing this compound, is to mix intimately 36 parts of clean iron filings with 21 of flowers of sulphur, and throw them by small portions at a time into a red hot crucible.

† It may be proper to state here that writers usually recommend great caution in manipulating with this gas, as it is usually reputed to be a powerfully sedative poison. I think, however, that its dangerous properties have been considerably exaggerated, as no particular caution has ever been observed in its use in my laboratory, and no accident has occurred there from it.

‡ This reagent, when recently prepared, is colorless, but, after standing a while, becomes yellow or even red from separation of sulphur. The latter modification differs, in some essential particulars, from the former.

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phides will be dissolved. The solution is separated by filtration from the precipitate, care being taken to wash the latter thoroughly with water charged with sulphide of ammonium. The clear filtrate is now mixed with excess of dilute hydrochloric acid, and a little water saturated with sulphureted hydrogen. The sulphides are re-precipitated, and after being thoroughly washed, are agitated with a solution of carbonate of ammonia, which must be allowed to remain on them, at a gentle heat, for about fifteen minutes. The solution contains the *arsenic*, if any be present, and it will be detected by the yellow precipitate which falls when a stream of sulphureted hydrogen is passed through the liquid, after it has been acidulated with dilute hydrochloric acid. The precipitate, after being washed with solution of carbonate of ammonia till a yellow precipitate is no longer produced by sulphureted hydrogen, is dissolved off the filter in the smallest possible quantity of aqua regia. The solution is now boiled for a while with carbonate of ammonia in excess, and acidulated and precipitated as before, should this precipitate be any other color but orange, it is because of the presence of gold or copper. In this case, it must be collected on a filter, washed, boiled with strong water of ammonia, treated with a few bubbles of sulphureted hydrogen and filtered. To the clear solution dilute hydrochloric acid must be added, and a stream of sulphureted hydrogen passed through it, when an orange precipitate proves the presence of antimony.

That portion of the precipitate which remained undissolved in sulphide of ammonium is now examined by heating it to boiling with dilute nitric acid, after having

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first thoroughly washed it. The solution may contain the oxides of lead, bismuth, cadmium and copper. It is evaporated to a small bulk, mixed with dilute sulphuric acid, allowed to stand for some time and filtered from any precipitate of sulphate of *lead* which may have fallen. The solution is now mixed with ammonia till the liquid smells strongly of it. Should a precipitate fall, it is *bismuth*. This may be proved by dissolving the precipitate in dilute nitric acid, adding a little hydrochloric acid, evaporating to dryness, re-dissolving in a little water, very slightly acidulated with hydrochloric acid, and then adding much water, when a milkiness indicates the presence of the last named metal. The solution, filtered from the precipitate of bismuth, is now to be acidulated slightly with dilute hydrochloric acid, and saturated with sulphureted hydrogen. The resulting precipitate must be thoroughly and rapidly washed, and then boiled in dilute sulphuric acid. The resulting solution is quickly filtered from the insoluble matter, when, if *cadmium* be present, it may be known by the yellow precipitate which sulphureted hydrogen throws down from the clear filtrate. The *copper* remains on the filter as a sulphide, and may be recognized by the tests already given.

We now return to solution No. II., which is evaporated till it no longer smells of sulphureted hydrogen, mixed with concentrated nitric acid, and evaporated to dryness on a sand bath. The residue is digested with hydrochloric acid on a sand bath until it is white. The solution is filtered from the insoluble silica; chloride of ammonium is added, then strong solution of ammonia,

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and lastly sulphide of ammonium, and the whole is boiled and filtered. The precipitate is thoroughly washed and heated with dilute hydrochloric acid. Should a residue remain insoluble, it probably contains cobalt or nickel. The whole is now to be boiled with nitric acid, diluted with water, filtered, mixed with excess of potassa, boiled and filtered.

The precipitate, after being well washed, is dissolved in warm, dilute hydrochloric acid, mixed with chloride of ammonium and excess of ammonia, and rapidly filtered. Before this is done, a portion of the precipitate should be dried, and fused, before the blowpipe, on platinum foil with nitre and carbonate of soda. A green color indicates *Manganese*. The fused mass is dissolved in water, the solution acidified with acetic acid, and mixed with a solution of acetate of lead, when a yellow precipitate will prove the presence of *chronium*. The precipitate from the last addition of ammonia is dissolved in dilute hydrochloric acid, and tested with ferrocyanide of potassium. A blue color is characteristic of *Iron*. The ammoniacal solution is acidified by hydrochloric acid, mixed with excess of carbonate of ammonia and boiled. If a precipitate fall, it is probably Manganese, and may be tested, as already mentioned, by the blowpipe.

If any cobalt and nickel be present, they are contained in the solution, which is to be mixed with solution of cyanide of potassium as long as any change of color is observed; then treated with excess of hydrochloric acid and boiled till no more fumes of hydrocyanic acid are given off. Potassa is now added in excess, and the

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solution is boiled till no more ammonia escapes. The precipitate is probably oxide of *nickel*, which must be tested before the blowpipe. The solution is now acidulated with nitric acid, evaporated to dryness, the residue fused for some minutes, allowed to cool, and then heated with water. Should a black substance remain, it is well washed, dried, and fused in the blowpipe flame with potassa. A blue color indicates *cobalt*.

The colored residue from solution No. II. is now mixed with about four times its weight of a dried mixture of the carbonates of potassa and soda, and placed in a porcelain crucible, which is itself enclosed in a Hessian crucible. If it is desired to protect the porcelain crucible as fully as possible from too sudden changes of temperature, the Hessian crucible may be filled with calcined magnesia, which is to be rather tightly packed. This precaution, however, is not absolutely necessary, though by furnishing a more equable heat to all parts of the inner crucible, it diminishes the risk of fracture. The outer crucible is now covered with a small piece of brick, which should fit it with tolerable accuracy, the inner crucible having been closed with its own appropriate lid. Thus prepared, the crucible is introduced into the fire of a forge, or even a common coal stove, and heated gradually to bright redness. This temperature is to be maintained for about twenty minutes, when upon the withdrawal of the crucible, the mixture within will be found fused to a glass, with a smooth, depressed surface. Should this not be the case, it is an indication that the substance has not been sufficiently heated, in which case it must be returned to the fire, and kept

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there till it assumes the appearance described, and then allowed to cool.

The porcelain crucible is now removed, carefully freed from every adhering particle of magnesia, placed in a large beaker, and digested with distilled water in a warm place. As soon as the fused mass is loosened, it is removed, and its lower surface examined for globules of metal, which, however, will rarely, if ever, be found, should the preceding operations have been properly conducted. The fused mass should be treated first with nitric and then with hydrochloric acids, and examined precisely in the manner already described for the original ore.

If it be desired to ascertain the earthy constituents of the ore, a matter of no little importance to the smelter, a further series of operations will be necessary. A portion of the solution resulting from the ebullition with potassa, in solution No. II., is tested for *alumina*, by mixing it with excess of ammonia, and heating it, when, if that earth be present, a white precipitate will fall. If, after filtering, the clear solution give a white precipitate with sulphide of ammonium, the ore contains *zinc*.

The other earths will be found in the precipitate obtained by the addition of potassa. After dissolving it in hydrochloric acid, precipitating with chloride of ammonium and excess of ammonia, the earth, should no phosphates be present, will be found in the solution. Should phosphates be present, it will be necessary to dissolve the precipitate in dilute hydrochloric acid, mix the solution with acetate of potassa, add sesquichloride

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of iron till a red color appears, boil and filter. The phosphoric acid remains with the iron upon the filter, while the chlorides of the earth pass through, and are found in the filtrate.

They are easily detected by the following process: If the solution be colored, it must be mixed with chloride of ammonium, ammonia, and sulphide of ammonium, boiled and filtered, care being taken that during the whole process it smells strongly of the last named reagent. The clear solution is boiled to expel sulphide of ammonium, and mixed with excess of carbonate of ammonia. The white precipitate is collected on a filter, and the solution treated with phosphate of soda. A white precipitate indicates *magnesia*. The precipitate is dissolved in dilute hydrochloric acid, and divided into three parts. To the first portion, sulphate of lime in solution is added. An immediate white precipitate indicates *baryta*. The second portion is mixed with a saturated solution of sulphate of potassa, and allowed to stand till the precipitate settles, care being taken to add enough thoroughly to precipitate all the baryta and strontia present. The mixture is now filtered, and ammonia and oxalate of ammonia added to the filtrate. A white precipitate shows the presence of *lime*. The third solution is mixed with excess of hydrofluosilicic acid, filtered if necessary, evaporated to dryness, and extracted with water, which must remain a long time in contact with it. The solution thus obtained is filtered, mixed with sulphate of lime in solution, and allowed to stand for some time, when, should a precipitate form, it is indicative of *strontia*.

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QUANTITATIVE ANALYSIS.

Copper is commonly estimated in the form of oxide, and the agent used to precipitate it from its solutions is a solution of pure caustic potash. Some precautions are necessary in order to insure the success of this process. The copper solution is boiled in a porcelain or platinum capsule, and the potash is added during ebullition, till it no longer produces a precipitate. Oxide of copper falls in the form of a heavy brownish black powder.

Before filtering, it is necessary to dilute the liquor and boil it, for if it be too concentrated, some hydrated blue oxide remains suspended in the solution, and is not precipitated by boiling. The boiling also is essential, for should potash be added to a solution of copper in the cold, the precipitate is blue, bulky, and mixed with alkali, which it is very difficult to wash out. Boiling will convert this loose hydrate to the dense black protoxide.

In any case, protoxide of copper is very difficult to wash, but it may be entirely freed from potash by using hot water. The cleansing is facilitated by filtering in an atmosphere of steam. This is conveniently done in Normandy's filtering apparatus,* but any person of common ingenuity will be able to contrive means of accomplishing this. After complete washing, the precipitate is thoroughly dried. For this purpose, I am in the habit of employing an air oven, attached to my stove. It is made of sheet iron, and fitted in the stove under the

* See Normandy's edition of Rose's Treatise on Chemical Analysis, vol. ii. p. 33.

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pipe. It is provided with several sheet iron shelves, perforated with holes to receive the necks of the funnels.

After drying, the filter is removed from the funnel, and separated from the precipitate. This is best accomplished by placing the platinum crucible in which the ignition is to be performed, on the central angles of four quarter sheets of glazed paper, laid together, and emptying the precipitate into it. Some of the oxide will adhere to the filter; this is to be removed by gently rubbing the filter between the fingers, over the crucible. With all these precautions, some small particles of the oxide will still adhere to the filter. To avoid the loss of these, the filter is to be cut up with a sharp pair of scissors, and dropped into the crucible, or it may be burned separately upon the cover, or still better, rolled into a corner, wrapped with a few turns of thin platinum wire, and burned in the open air. The crucible is now removed to the centre of one of the pieces of paper, and the oxide which has been spilled, carefully tilted into it.

The ignition may be accomplished either over an alcohol lamp, over gas flame, or in the furnace. Should the former be preferred, a Berzelius or Rose lamp should be selected. The flame at first should be very low, until the paper has been slowly charred, after which it is to be gradually raised till the crucible is red hot, and kept at that till the paper has burned white. Care must be taken that the white flame of the lamp does not touch the sides of the crucible, or it will injure the metal. If the fire be chosen, the crucible must be placed in a Hessian crucible, lined with magnesia, as already described.

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The ignition of the filter will usually reduce a portion of the oxide to the metallic state; but this may easily be oxidized by directing a current of air upon it during the ignition. Sufficient draft for this purpose may be obtained by placing in the crucible a piece of platinum foil in the form of a partition. A still better method is to allow the whole to cool, to moisten with a few drops of nitric acid, and then to ignite the second time.

After ignition, the crucible must be weighed as soon as possible, or it will absorb water from the atmosphere. It should not be weighed hot, but immediately after cooling. It is best to cool it under a bell glass, supported over a dish of concentrated sulphuric acid. Every 100 parts are equal to 79.83 of metallic copper.

Sometimes the potash does not precipitate all the copper from its solution, a state of affairs which may be recognized by the brown discoloration of the liquid produced by sulphide of ammonium. Again, after protracted boiling with potash, some protoxide of copper adheres to the sides of the capsule in which the precipitation has been effected, and cannot be separated by mechanical means. When this occurs, the adhering oxide must be dissolved in a little dilute sulphuric acid, and precipitated as before, water being previously added. In very dilute solutions, this accident never happens.

This process can be used in ammoniacal solutions, provided they be well boiled and rapidly filtered from the precipitate. If the ammoniacal liquor be allowed to stand too long upon the precipitate, it will inevitably

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re-dissolve some of the oxide, and the liquid would become blue. It should be altogether colorless during the filtration.

Carbonate of potash cannot be substituted for caustic potash in these determinations, because it leaves in solution some protoxide of copper, which can only be separated by evaporating the liquor to dryness, and igniting the salt.

The copper may also be determined in the metallic state by introducing into the solution a perfectly clean, polished piece of metallic iron. Much objection has been made to this process, on various grounds, by different chemists. It has been said that it is liable to be contaminated with the carbon and fibrous flakes of iron, which will vitiate the result, and that in drying it, a suboxide of copper will be formed, which will exaggerate the per centage.

These objections may be of force in the more delicate determinations of copper, when absolute scientific accuracy is required, but as far as the commercial analysis of ores is concerned, they have no substantial foundation, if proper care be taken. In the first place, rolled iron should not be employed, or the carbon separated will be considerable, and the fibrous pieces detached during the operation, numerous. I am in the habit of using bright piano wire, which I roll into a spiral coil, and introduce into the liquid. Secondly, the solution of copper must be dilute, and decidedly acid. If it be too concentrated, all the copper will not be precipitated, and if it be not sufficiently acidulated, an insoluble basic salt of iron will mix with the copper, and ruin the

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analysis. Thirdly, the precipitate, after being thoroughly washed, must be dried, at a very moderate heat. Mitchell says it must not be raised above 212°. I have been in the habit of drying my precipitates in an air oven, at a temperature of about 150° F., and I have never been troubled with oxidation.* Fourthly, there must be no free nitric acid in the solution; and, lastly, the precipitate must be very thoroughly washed.

Mitchell prefers zinc to iron for these operations, but I am of different opinion. I have frequently used the zinc, and have always been disappointed. It throws down the copper in a pasty state, from which the zinc salt is not easily separated, and which, owing to its extremely minute division, oxidates rapidly, during drying. Mitchell's reason for preferring the zinc, is the supposed contamination of the precipitated copper by the separated carbon and detached fibres of the iron. This, however, depends entirely upon the kind of iron operated with, and the acidity of the solution. If bar iron or cut nails be used, the operator will have trouble enough from this source; but should he employ good clean piano wire, he will not be able to estimate or detect the carbon. It is also desirable to use large excess of iron, as then there will be no risk of annoyance from little detached filaments of that metal, and if the solution have been properly acidulated, the copper will separate in brilliant scales, the under surface of which

* Even if oxidation should take place, the assayer need not reject his result, and so lose his labor. The error is easily rectified by placing the whole in a tray of platinum foil, introducing it into a tube of hard glass, and igniting in a current of washed hydrogen gas.

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coming off from the iron, will be clean and polished. If, however, bar iron have been employed, or too much acid used, the under surface of the copper is frequently black with carbon, and roughened by detached fibres of iron. Under such circumstances, it is needless to say that the process cannot be relied upon, for though the iron may be separated by dilute hydrochloric acid, some loss of copper will probably ensue, and the carbon cannot be got rid of. If the solution be only slightly acidulated, a sort of galvanic action sometimes takes place between the iron and the first particles of copper precipitated, so that the copper is deposited in a firm sheet, and sometimes is so closely adherent to the positive metal as to be inseparable from it by mechanical means. If, on the other hand, the solution be too strongly acid, there is more danger from contamination from carbon.

The time taken up by this process varies with the temperature at which it is conducted. If the precipitation takes place at the common temperature of the air, it will require from twelve to twenty-four hours for its completion. The heat of a sand bath accelerates the deposition of the copper, and if the solution be made to boil, all the copper is thrown down in an hour. The operator usually determines the end of his process by the solution becoming colorless, or assuming a scarcely perceptible beryl green hue. A better plan, however, is to introduce a piece of clean polished iron into the solution. If, after some minutes, it remain uncolored, the copper may be considered precipitated.

Levol suggested a method of estimating the quantity of copper in a solution containing it, which is employed

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by many chemists. After getting the nitric or nitro-muriatic solution, he supersaturates with ammonia, and pours it into a flask or bottle, which can be closed air-tight with a ground glass stopper, or in any other way. Cork must not be used for this purpose, as its porous nature allows air to traverse it, and so vitiates the result. Some operators close the mouth of the vessel by tying a bit of sheet India rubber over it, so as thoroughly to exclude the air. Should the ammoniacal liquor fail to fill the bottle, water, from which all atmospheric air has been excluded by recent boiling, is introduced till the vessel employed is completely filled. A clean, bright blade of pure copper, which has been carefully weighed, is now introduced into the whole length of the vessel, which is immediately closed. The whole is set aside till the liquor becomes colorless, in consequence of the formation of a suboxide of copper by the action of the metal upon the protoxide in solution. The blade is then quickly withdrawn, washed in distilled water, dried, and weighed. The loss sustained by the blade indicates the amount of metallic copper present, for $CuO+Cu=Cu_2O$. One equivalent of copper has abandoned the blade and formed a suboxide.

I have never been able to get good results from this process. It is, in the first place, extremely tedious. Its author says it is finished in four days, but I have had bottles standing on my shelves for two weeks in hot summer weather, and still remaining blue. Some chemists say that the process can be greatly hastened, so as to be completed in an hour or two, by closing the mouth of the vessel with sheet caoutchouc, and heating

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in a water bath. This method is manifestly inapplicable in the presence of silver, and other metals, soluble in ammonia and precipitable by metallic copper.

Cassaseca proposed a method which can only be regarded as a rough approximative estimation. He compares the tint of an ammoniacal solution of the substance under examination with that of another ammoniacal liquid containing a known weight of pure copper.

Copper is also precipitated as sulphide by sulphureted hydrogen, or by an alkaline sulphide. It cannot, however be weighed as a sulphide, because in drying, and even during washing, it absorbs oxygen from the air. For this reason, it is dissolved in aqua regia or nitric acid, and precipitated as oxide.

Pelouze contrived a volumetrical process for estimating this metal. It consists in precipitating the copper from its ammoniacal solution by means of a standard solution of sulphide of sodium. This salt, the colorless crystallized hydrosulphate of commerce, is dissolved in distilled water, and introduced into a graduated tube or burette, divided into tenths of cubic centimetres. To determine the value of this standard solution, it is necessary to dissolve a certain quantity of pure copper,* say a gramme, in pure nitric acid, and supersaturate it with ammonia until a perfectly clear blue solution be obtained. This is raised to the boiling point, and the test solution dropped into it. The copper is precipitated as sulphide, and the liquor gradually fades.

* That obtained by the electrotype process is generally preferred.

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Dilute water of ammonia is added from time to time, to replace that which is lost by evaporation, and towards the close of the operation, the solution is let fall from the burette, in single drops, the flask containing the copper salt having been shaken repeatedly during the operation. As soon as the solution is completely decolorized, the number of degrees is read off from the burette, and recorded, for the sake of comparison.

The substance to be examined is now dissolved in aqua regia, treated with ammonia, and decolorized, precisely in the same manner as the solution of pure copper. The decrease in the blue color indicates the progress of the precipitation, and as the period of complete decoloration approaches, it is desirable to add the test solution in drops, or even to employ the same solution more largely diluted with a known quantity of water. The number of degrees must be read off as soon as the decoloration is accomplished, because the precipitated sulphide is soon oxidated to sulphate, which is again dissolved in the ammonia, rendering it blue, so that the operator, who delays too long, will go on re-precipitating the same copper, and getting, of course, too large a per centage.

A comparison of the two readings of the burette will give the proportion of copper in the substance analyzed. Thus, if 500 measures of the test solution decolorize an ammoniacal liquor containing one gramme of pure copper, and the liquid under examination require 480 measures to discharge its color, it follows that it contains $\frac{480}{500}$ or 0.96 of a gramme.

This method, according to the author, is liable to

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error of not more than five or six thousandths. It is not interfered with by the presence of tin, zinc, cadmium, lead, antimony, iron, arsenic, or bismuth, as the copper always falls before these other metals. Indeed, it has been asserted that when the sulphurets of zinc, cadmium, tin, lead, antimony, and bismuth, are placed in contact with an ammoniacal solution of sulphate of copper, they decolorize it, which proves that they cannot exist, except for a moment, in a solution of copper. Iron should be peroxodized before the addition of the ammonia, by ebullition with nitric acid, unless the solution should have been made in aqua regia.* It need not be filtered, some chemists say; but it is a slovenly way of working to decolorize a solution with a large magma diffused through it. Should there be a large quantity of iron present, the solution must be filtered, or it will be impossible accurately to determine the moment of decoloration, and in all instances it is best to filter. The other sulphurets go down after the copper. If *zinc* alone be present, a white precipitate falls; if cadmium, a brilliant yellow one goes down immediately after the decoloration has been effected by the precipitation of all the copper.

This method is of course inapplicable in the presence of cobalt, nickel, and mercury, and also when silver is mixed with the copper. The latter metal, however, can easily be separated by hydrochloric acid and filtration, before the ammoniacal solution is made.

It is necessary, in all cases, to estimate the strength

* This is a matter of great importance, for should any of the iron remain in the form of protoxide, it will vitiate the result, that oxide being, to a certain extent, soluble in ammonia.

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of the standard solution of sulphide of sodium, before each series of analyses, for this substance is slowly oxidated by exposure to the air, and consequently becomes weaker as it grows older.

SEPARATION OF OXIDE OF COPPER FROM OXIDE OF BISMUTH.

The agent commonly employed in separating copper from bismuth is *carbonate of ammonia*, which when added in excess, dissolves the copper and throws down the bismuth. After the precipitation, it should not be immediately filtered, but should be allowed to stand for some time in a warm place, to enable the oxide of bismuth completely to subside. The latter oxide is to be well washed on the filter with carbonate of ammonia. The filtrate is now evaporated at a gentle heat, to expel the excess of carbonate of ammonia, treated with ammonia and precipitated, as already described, by caustic potash. The oxide of bismuth is ignited and weighed. This method is not unexceptionable, it being difficult to separate the last traces of copper from the bismuth.

Cyanide of potassium has been used for this purpose. A slight excess of carbonate of ammonia having been added to the solution of the two oxides, it is heated with cyanide of potassium. Carbonate of bismuth falls, and the copper remains in solution. The mixture is filtered, the filtrate evaporated with sulphuric acid, to expel the hydrocyanic acid,* and the copper precipitated by caustic potash.

* This operation should always be performed under a hood, in a strong draught, as the fumes of the hydrocyanic acid are a deadly poison. If the operator has no hood, he should work in the open air, or with his back towards a strong draught.

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Another method is to precipitate the two metals as sulphides, and having well washed and weighed the mixed sulphides, to introduce them into a glass tube, connected at one end with an apparatus for generating *chlorine*, and at the other, by means of a bent tube dipping under the surface, with a vessel containing water acidulated with hydrochloric acid. A stream of chlorine being passed, the sulphides are heated by a spirit lamp, first gently, and afterwards to redness. The sulphides are thus converted to chlorides. The chloride of bismuth, being volatile, distils over and is dissolved in the acidulated water, while the fixed chloride of copper remains in the tube. It is to be washed out with a little dilute nitric acid, evaporated with sulphuric acid, and estimated as before.

If the substance treated be an alloy, it may be directly acted upon by the chlorine.

SEPARATION OF PROTOXIDE OF COPPER FROM PROTOXIDE OF LEAD.

Copper is often separated from lead by boiling the solution of the mixed oxides with one of *caustic potash*. The process is an imperfect one, leaving always some lead mixed with the copper.

Carbonate of ammonia has been employed for the same purpose. The solution is mixed with excess of this reagent, carbonate of lead is precipitated, and copper remains in solution. A portion of the copper, however, goes down with the carbonate of lead, giving a greenish hue to that salt, which, when pure, is of a clear, brilliant white.

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Sulphuric acid is the agent commonly employed for this purpose. Into the concentrated solution dilute sulphuric acid is poured as long as a precipitate falls; alcohol is then added. The precipitate is collected on a filter, and washed, first with dilute sulphuric acid, and then with alcohol. Sometimes, after the precipitation, the whole is evaporated to dryness, and the mass heated to expel excess of sulphuric acid. This is thrown upon a filter, well washed, dried, and ignited, and the copper is subsequently precipitated with potash. If the alcohol have been used, it is necessary first to evaporate the copper solution, so as to expel this volatile liquid before precipitating with potash.

A little lead may escape, as the sulphate of this metal is not altogether insoluble in water. This, however, will always be found, if the process has been carefully conducted, in the filtrate from the precipitated oxide of copper, and may be precipitated as oxalate by *oxalate of ammonia*, after having previously neutralized the solution with a little dilute acid.

Cyanide of potassium is used for separating lead, in the same manner as already described for bismuth. Copper has also been separated from lead by using *hydrochloric acid*, and precipitating the last traces of chloride of lead with a strong alcohol. The rest of the process is conducted as before described, when speaking of the management of the sulphuric acid process with alcohol.

SEPARATION OF OXIDE OF SILVER FROM OXIDE OF COPPER.

Silver is easily separated from a solution of the mixed oxides in nitric acid by the addition of *hydrochloric acid.*

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The chloride of silver is collected on a filter, washed by a continuous stream of water, dried, and fused in a porcelain crucible. The copper is precipitated from the filtrate by potash.

Or the solution of metals may be treated with *cyanide of potassium* till the precipitate first formed is entirely re-dissolved, the solution having previously been neutralized with potassa. On the addition of pure nitric acid to the clear solution, all the silver is thrown down as cyanide. The filtrate is evaporated with sulphuric acid, to expel hydrocyanic acid, and the copper precipitated as oxide by potassa.

Fresenius uses this reagent somewhat differently. Having obtained the cyanide solution, he passes through it a stream of sulphureted hydrogen, which throws down silver only, provided enough cyanide of potassium be present. The solution is filtered from the sulphuret of silver, heated to expel sulphureted hydrogen, treated again with cyanide of potassium, evaporated with a mixture of sulphuric and nitric acids, and precipitated with potassa.

SEPARATION OF COPPER FROM MERCURY.

When the mixed oxides are dry, they are easily separated by *ignition*, the mercury volatilizing, and leaving the copper. When in solution, the mixed oxides may be treated with cyanide of potassium, in the manner already described for silver. Sulphureted hydrogen, passed through this solution, throws down the mercury alone.

Formiate of soda is another agent which has been

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employed for the separation of these oxides. To the solution containing the *oxide* of mercury, (if it is a suboxide, it must be converted into the oxide by boiling with nitric acid,) hydrochloric acid is added, and then potassa nearly to neutralization. Formiate of soda is added, and the whole is digested for several days at a temperature of from 90° to 108°, care being taken that the temperature last named be not exceeded. The mercury falls as a subchloride, which is to be collected upon a weighed filter. As some mercury may escape, the filtrate is treated in the same manner as the original solution, allowed to stand for twenty-four hours, and any precipitate which may fall, added to that already on the filter. The chloride is dried at a very gentle heat, and weighed. The copper is precipitated, as oxide, from the filtered liquor, by hydrate of potash.

SEPARATION OF OXIDE OF COPPER FROM OXIDE OF CADMIUM.

Carbonate of ammonia in excess is added to the solution; carbonate of cadmium and oxide of copper, with a little oxide of cadmium, remains in solution. If this solution be exposed to the air, the oxide of cadmium is all deposited, and oxide of copper alone remains in solution, which is precipitated as before.

Cyanide of potassium may be employed by adding this reagent till a clear solution be obtained. Sulphureted hydrogen is passed through the mixture, sulphuret of copper remains in solution, and sulphuret of cadmium falls. The solution is boiled, to expel excess of sulphureted hydrogen, some cyanide added, and the hy-

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drocyanic acid driven off by evaporation with sulphuric acid, or by boiling with hydrochloric acid, nitric acid being added from time to time, as long as any hydrocyanic acid is given off. The copper is then precipitated as oxide.

SEPARATION OF OXIDE OF COPPER FROM THE OXIDES OF URANIUM, NICKEL, COBALT, ZINC, IRON, AND MANGANESE, AND FROM THE EARTHS AND ALKALIES.

The method usually adopted for the separation of oxide of copper from the above named oxides, the sulphurets of which are soluble in dilute acids, is to precipitate as sulphuret by a stream of *sulphureted hydrogen* passed through an acid solution.

Some precautions must be observed in order to secure satisfactory results. In the first place, if the solution be, as it generally is, a nitro-muriatic one, it must be evaporated with repeated additions of hydrochloric acid, to expel free nitric acid, for if any of the latter solvent remain, it will act upon the recently precipitated sulphuret of copper.

The sulphureted hydrogen must be passed till no further precipitate falls, and till the solution smells strongly of this reagent. The precipitate must be rapidly filtered, and washed uninterruptedly, because if it remain any length of time exposed to the air, it absorbs oxygen, and is partly converted into sulphate of copper, which passes through the filter, and turns the filtrate brown, in consequence of a re-precipitation of the sulphate of copper by means of the sulphureted hydrogen it still holds in solution. It is advisable,

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indeed, to wash it with water charged with sulphureted hydrogen, which decomposes the sulphate on the filter as fast as it is formed. During the whole process the solution and precipitate should smell strongly of this gas.

Various methods have been adopted for the disposal of this sulphide. It cannot be weighed as sulphide, because a portion of it must be oxydated in drying. It is, therefore, to be converted into oxide. To effect this, some roast it in a platinum or porcelain crucible, first at a low red heat, then at a little higher temperature, finally raising the whole to whiteness, to expel the last trace of sulphuric acid. This method cannot be trusted, because we can never be sure that there is not some undecomposed basic sulphate left behind, nor that some suboxide has not been formed during the process. It is, therefore, advisable to dissolve it in some hot aqua regia, and precipitate the oxide of copper with hydrate of potash.

Some chemists, after having thoroughly washed the sulphide of copper, introduce a clean beaker under the funnel, perforate the bottom of the filter, and wash down the sulphide with distilled water. The precipitate is then treated as before with aqua regia.

Others allow the precipitate to dry till it can be easily separated from the filter. It is then detached, and treated again with aqua regia. The filter, which retains a little sulphide, is burned, and its ash, dissolved in aqua regia, added to the solution of the precipitated. The whole is then filtered and precipitated.

It is a bad plan to digest the filter with the precipitate in nitric acid or aqua regia, because the action of

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the nitric acid on the paper, generates an organic compound which materially interferes with the precipitation by solution of potash. When this has been done inadvertently, the solution is to be evaporated to dryness with sulphuric acid in slight excess, the resulting sulphate of copper dissolved in water and precipitated with potash.

It should be remarked that this process, though commonly adopted, is not applicable when zinc and nickel are present, because appreciable quantities of these metals always go down along with the copper. To meet this difficulty, M. Flajolot has indicated a method of accomplishing this by means of *hyposulphite of soda*, or of *sulphurous acid solution of iodine*.

The former reagent is employed in the following manner: The solution must contain neither hydrochloric nor nitric acid, both of which are expelled by evaporation with sulphuric acid. Water is then added, and a solution of hyposulphite of soda poured into the solution of the mixed oxides, kept at the boiling point, till it no longer produces a black precipitate. The complete precipitation is known by the subsidence of the subsulphide of copper and the absence of suspended sulphur in the supernatant liquor. This precipitate is collected on a filter, washed with boiling water, and treated as already described, to convert it into oxide of copper. The zinc, nickel, or cobalt, is precipitated with carbonate of soda from the filtrate from the subsulphide of copper.

By this method copper may be separated from all those metals which are not precipitated from their acid solutions by sulphureted hydrogen.

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The second process is conducted as follows: The substance containing the copper is dissolved in nitric acid, the solution evaporated so as to drive off the greater part of the excess of acids; water is then added, and if antimony be present, tartaric acid. Should a residue remain after digestion, it is filtered, and to the clear solution are added, first, sulphurous acid, and then iodine dissolved in sulphurous acid. This last must be poured in in small portions, and the operator should stop as soon as the precipitate ceases to fall. The liquid should be allowed to stand at least twelve hours before filtering, and this last operation must be very cautiously conducted, as the iodide of copper has a tendency to rise and run over the edge of the filter.

The iodide thus obtained may be dried at a steam heat, and then weighed; or it may be dissolved in aqua regia, like sulphide of copper; or it may be dissolved in ammonia, exposed to the air some hours, so as completely to oxidize the product, and filtered; or, finally, it may be introduced into a matrass, and dissolved in a stream of chlorine. In whatever manner the solution be effected, the copper is precipitated and weighed as oxide.

Berthier separates oxide of copper from the oxides under consideration, by boiling the solution with excess of *sulphite of ammonia.* Copper alone is precipitated as a subsulphite.

A very common, but altogether objectionable, method of separating copper from iron, is to precipitate the iron, as sesquioxide, with ammonia. Copper remains in solution, and the whole being thrown on the filter, the precipitate is thoroughly washed, dried, ignited, and

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weighed. The copper is then estimated as oxide, in the manner already described. A notable proportion of copper is lost by this process, since it goes down entangled with the iron, and escapes the ammoniacal solvent. I have repeatedly tried it upon weighed mixtures of pure copper and iron, and have invariably got an excess of the last named metal, in spite of the most careful washing. In some instances this has amounted to nearly two per cent.

The process of precipitating the copper, in the metallic state, with iron wire, is quite applicable to its separation from these metals, since none of them are thrown down by iron.

Hautefeuille recommends the following process of separating copper and zinc in the analysis of alloys of those metals: One gramme of the alloy is treated with nitric acid, and ammonia added to precipitate any tin, lead, antimony, or iron, that may be present. Acetic acid is now added in excess, and a sheet of lead suspended in the solution, the whole being kept boiling for two hours, after which time the liquid will be colorless, the copper being precipitated as metal upon the surface of the lead. In adopting this plan, arsenic must first be got rid of by a known weight of litharge.

SEPARATION OF GOLD FROM COPPER.

Gold is frequently separated from copper in the dry way, by *cupellation*, a process which will presently be described.

It may be conveniently separated by *sulphate of iron.*

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This salt ought to be of a beryl green hue approaching blue; should it be yellowish green, it contains oxide of iron, which somewhat delays the determination of the precious metal. The solution of *aqua regia* is repeatedly evaporated to dryness with hydrochloric acid, till all traces of nitric acid have been expelled; the residue dissolved in water, and solution of sulphate of iron added to it so long as a precipitate falls. The solution of the mixed metals should be kept decidedly acid during the entire process. Gold is precipitated, and copper remains in solution.

Oxalic acid may be added to the acid hydrochloric solution of the mixed metals, the same precautions being observed in regard to the expulsion of nitric acid. A slow evolution of carbonic acid takes place; gold is precipitated, and copper remains in solution.

Or, the acid solution may be just neutralized with soda or potash, and sulphurous acid being added, the whole is boiled, the gold being precipitated and the copper remaining in solution.

SEPARATION OF COPPER FROM ANTIMONY, ARSENIC, TIN, PLATINUM, GOLD, IRIDIUM, TELLURIUM, TUNGSTEN, VANADIUM, AND MOLYBDENUM.

The sulphides of the metals above enumerated, being all soluble in alkaline sulphides, a simple process suffices to separate them from copper. The solution having been carefully neutralized, is precipitated with sulphide of potassium. The metals above named all remain in solution, while sulphide of copper goes down mixed with the sulphides of metals the separation of which from copper we have already studied.

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The common method is to precipitate the copper from the acid solution with sulphureted hydrogen, and then to boil the mixed sulphides with yellow sulphide of ammonia, as already described under the head of Qualitative Analysis. The objection to this process is, that sulphide of copper not being entirely soluble in sulphide of ammonia, some of that metal is lost.

We shall make a few remarks on this subject under the next head.

ASSAY OF COPPER.

The term assay is applied both to the dry and the wet method of determining the quantity of metal in an ore or an alloy. The classification of ores, however, is generally based upon the convenience of the dry assay. For this purpose, copper compounds are classified as ores and alloys. The ores are distributed under three heads.

I. Substances which are entirely free from sulphur, selenium, and arsenic, and contain no other metal but iron.

II. Substances which contain sulphur or selenium, but no foreign metal but iron.

III. Sulphides which contain various metals.

For the performance of the dry assay, certain articles of laboratory furniture are indispensable. The operator should have a good wind furnace. One fourteen inches square by twenty-four deep, with a chimney thirty feet high, will give heat enough for an iron assay. A very good size for a copper furnace is nine inches square by sixteen deep. This will give a sufficient

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body of coal for ordinary purposes. It is well enough to have another furnace of the same length and breadth, but only six or eight inches deep, with the flue opening as near as possible the top. An iron plate covers the furnace, forming a sort of table over the flues, and the upper openings are closed by sliding plates. The flue ought to have a chimney to regulate the draught. When these conveniences are not to be had, a copper assay can be made in a cylinder anthracite stove, provided it has a strong draught, or even in a smith's forge. In the latter case, however, great care must be taken to avoid too high a heat.

The operator must, of course, have suitable tongs, pokers, &c., with iron rods flattened at the end, for the purpose of stirring the roasting ore. The crucibles employed may be either the common Hessian or the French of Beaufaye, which last are more durable, though this is a matter of no great consequence in a copper assay.

He must also be provided with finely powdered lime, kept in a well-stopped bottle; carbonate of soda, which has been dried by heating to low redness, also kept in the same way; fine powder of charcoal; dried borax and black flux. The latter is easily prepared by mixing two parts of argol, the crude tartar of commerce, with one of nitre, and igniting them with a red hot iron rod. Some other reagents in the dry way are used, which will be mentioned further on; but those just named are sufficient for most purposes.

The best fuel for the purposes of the assayer is coke. The firmest pieces are selected and broken into pieces

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about the size of small egg coal. It is well to have two sizes of broken fuel, one large, for the general heat, and another smaller, for fitting around the crucible. If the fuel be too small, the draught will be obstructed; if it be too large, it will be difficult to arrange it properly around the crucible. Charcoal or anthracite may be used if the operator cannot get coke; but the first is troublesome, because it burns out so rapidly that it requires constant replenishing, and the latter is annoying, on account of its propensity to split and fly. Bituminous coal is dirty and smoky, and its swelling interferes with the operation. The crucible is sometimes placed in a hollow in the fire, but more commonly it rests on a support of fire-brick, placed on the grate bars, and the fire is built up around it.*

ASSAY OF SUBSTANCES OF THE FIRST CLASS.

When the ores or slags of this class are tolerably rich, the assay is simple and easy. The substance is reduced to a fine uniform powder, by rubbing it up in a mortar, and passing it through a sieve. Should there be much metallic copper present, it will be very difficult to pulverize it, as it will flatten out in little sheets under the pestle. In this case, it is customary to separate these strips, and estimate the copper in them separately. It is then a simple calculation to apportion the per centage. If, however, the assay is to be made of the entire mass powdered, they must be thrown in.

The fine powder is now to be mixed with three times

* For further information on this subject, see my work on Dental Chemistry and Metallurgy.

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its weight of black flux, in a porcelain mortar, and poured into a crucible. The mortar is then to be rinsed out with black flux, which is to be added to the mixture already in the crucible, and then covered with a thin layer of the same flux, unmixed with ore. As the fusion of these ingredients will cause the mass to swell and bubble, care must be taken to select a crucible so large that it will be only half filled with the mixture.

The whole is then introduced into a furnace, which has been previously heated. The heat is gradually raised to bright redness. At this point, the mass becomes pasty, and begins to rise and fall, little puffs of vapor breaking through the imperfectly fused materials. Each jet of vapor burns with a violet flame, showing the combustion of the reduced and volatilized potassium of the black flux. When a mixture of carbonate of soda and powdered charcoal is substituted for this reagent, the flames are yellow. In about fifteen or twenty minutes the bubbling ceases, and the contents of the crucible sink down in tranquil fusion to the bottom of the pot. The surface of the flux is smooth, and marked with lines radiating from the centre to the circumference. An earthen cover is now put upon the crucible, and the heat is pushed nearly to whiteness, and kept at that for about ten minutes. At the end of that time it is withdrawn, and tapped gently on some hard substance, to cause the small globules of molten metal diffused through the slag to settle to the bottom. If the fusion has been carried far enough, the slag will have a smooth, shining surface, depressed in the centre.

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When the crucible is cold enough, it is broken, and the copper extracted.

If the operation has been successful, the button of copper has a clean, polished surface, and does not adhere to the crucible. Should it be marked by little depressions, it is an indication that the heat has been too high, and that some copper has been volatilized. The quality of the metal is tested by hammering it out upon a smooth anvil. If it is soft, yields easily, and flattens down without breaking at the edges, it is commonly regarded as pure copper, for iron usually renders it brittle. This is, however, by no means a universally reliable test. There are alloys of iron and copper which are malleable, and I have seen an assay button, containing 33 per cent. of iron, flatten out unexceptionably under the hammer. The proper plan, therefore, is to dissolve the button in aqua regia, and test for iron.

The quantity of ore to be employed for this purpose, varies with its richness. Of average ores, 200 grains are sufficient; while for poorer ores, 400 grains should be taken.

It sometimes happens that these ores of the first class are contaminated with some sulphur, in which case the copper button will be surrounded by a steel-gray investment of sulphide of copper. When this is the case, the ore must be treated in the manner presently to be described, under the head of Ores of the Second Class.

Slags are commonly assayed in this manner; but when they are poor, containing only two or three per cent. of metal, all the copper is not readily obtained,

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since the viscidity of the slag retains some of it, and other portions of it enter into chemical combinations with the various ingredients. Under these circumstances, it will be well to dissolve the slag, if soluble, in acids, and estimate the copper by the methods already described. It often happens, however, that slag is a definite silicate which will not dissolve in acid. In these cases, a moderate quantity—100 or 200 grains—is fused in a platinum or smooth porcelain crucible with twice its weight of dry carbonate of soda. The whole crucible is introduced into a beaker, containing distilled water, and digested at a moderate heat till the softened mass swells and separates readily from the crucible. It is then treated with aqua regia, in a flask or matrass, the solution transferred to a porcelain capsule, evaporated to dryness, moistened with hydrochloric acid, redissolved in water, and the copper estimated in the manner already described.

If, however, it be desired to determine it in the dry way, the substance may be fused at the high heat of an iron assay, the operation being considerably prolonged. When the crucible is removed and broken, a button, containing a large amount of iron, will be found. This is to be analyzed, as already described, in the humid way.

A better plan than this, is to sulphurate the poor slag or ore, as the globules of sulphuret are larger than those of metallic copper, and fall more readily through the melted slag. The metal is then obtained in the form of a flattened button of sulphide, the further assay of which is conducted as shall be described in the next

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section. This process, though tedious, yields better results than any other dry process for poor ores.

ASSAY OF SUBSTANCES OF THE SECOND CLASS.

Ores of this class contain sulphur, and sometimes selenium, are generally sulphides or sulphates, and are assayed either for regulus or matt, or for copper.

SULPHATES. With a reducing flux, the sulphates yield copper and a slag containing a double sulphide of copper and the alkaline metal of the flux. The more of the latter is employed, the less metal and the more sulphureted slag is obtained; but if it be only used in sufficient quantity to reduce the copper, the metal subsides pure, and a slag remains containing only sulphate.

"Thus, it has been ascertained that the neutral anhydrous sulphate of copper gives, firstly, 27 per cent. of copper, with three parts of black flux, (about two-thirds only of that which it contains,) and a black crystalline slag, containing much sulphur. Secondly, with two parts of the same flux, 37 per cent. of copper and a clean gray slag, containing very little sulphur. When but one part of black flux is employed, there is not a sufficiency of carbon to reduce the whole of the oxide, and only about 12 or 14 per cent. of metallic copper is produced, which is enveloped in a red, vitreous, opaque slag, composed of protoxide of copper and alkali, and above which is a layer of fused sulphate of potash, which is crystalline and colorless.

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"It may thus be seen that in order to extract the whole of the copper from a sulphate in this manner, that the proportion of reducing flux which will give the maximum result, and which will also produce a slag containing but little sulphur, must be arrived at by guess-work.

"The sulphates of copper, however, are completely decomposed by heat; and the easiest and best method of assaying them, is to expose them to a white heat in a platinum crucible till nothing more is given off. The residue is oxide, which can be fused with three parts of black flux, when all the copper contained in it is exactly and readily separated in the metallic state.

"The compounds of oxide of copper with sulphuric acid may be assayed by fusion in an earthen crucible with from one to two parts of carbonate of soda; the fused matter must be poured into an ingot-mould, pulverized, and re-fused in the same crucible, after mixture with its own weight of black flux. By fusion with carbonate of soda, the sulphate of copper is decomposed, and sulphate of soda and a compound of the oxide of copper and alkali formed, which is afterwards completely reduced by black flux, without the possibility of the formation of a sulphuret of copper."*

The sulphates of copper, however, being soluble in water, are more easily analyzed by the humid process. The substance is dissolved in hot water, filtered, well washed, acidulated with hydrochloric acid, and the copper precipitated from it by metallic iron.

* Mitchell's Manual of Assaying.

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SULPHIDES. *Fusion for Regulus or Matt.* This is a simple process, and easily performed by the merest tyro. All that is necessary is to mix the ore with its own weight of glass of borax, to introduce it into a crucible, and heat it to full redness. The gangue or vein-stone enters readily into fusion with the borax, and the sulphide or regulus subsides. Care must be taken in separating this from the crucible, as it is exceedingly brittle, and apt to stick to the sides and bottom. To obviate this, Berthier lined his crucibles with charcoal, which allows the button to be readily detached, when the crucible is broken. Phillips recommends the use of a common crucible, but pours the whole fused mass into an iron mould, of an elliptical form, from which the regulus is easily separated, by turning the mould over when cold, and giving it a few taps upon some hard body.

During this process, some sulphur is sublimed, whence it happens that the regulus contains less sulphur than the ore. It is manifest, therefore, that the proportion of vein-stone cannot be determined from the loss experienced in this fusion.

If the operator wishes to imitate the furnace processes, by using the fluxes employed in smelting on a large scale, such as quartz, baryta, lime, &c., the crucible must be lined and the heat that of an iron assay.

Assay for Copper. In order to estimate copper in the dry way in this class of ores, it is necessary first to roast them so thoroughly as to expel every trace of sulphur. In order to accomplish this, it is necessary first to reduce the ore to the finest possible powder, to intro-

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duce it into a crucible, and place the whole in a furnace, which should be at a low red heat. The crucible is laid slanting in the fire, the damper closed, and the ore stirred assiduously with an iron rod, so as continually to expose fresh surfaces to the air. It is essential that at this period the heat should be low, lest the sulphuret should fuse or at least agglutinate, a circumstance which would necessarily interfere with the oxydation. Blue flames of sulphur will be seen to play over the surface of the roasting mass, but they gradually give place to white fumes of sulphurous acid. These, in their turn, disappear, and the heat is slowly raised, the ore being constantly stirred. The operator, from time to time, holds a glass rod moistened with ammonia, over the crucible, to determine by the fumes, whether sulphurous acid continues to be given off. The heat is pushed now and then to full redness, which expels the sulphurous acid formed by the mutual reaction of the sulphides and sulphates. When the fumes on the rod dipped in ammonia are no longer visible, the heat is raised to whiteness in order to decompose the sulphates by driving off their sulphuric acid.

Mitchell objects to this process of roasting as inefficient, since some of the sulphates remain undecomposed even at this elevated temperature. To meet this difficulty, he proposes to stir in with the roasting ore, at full redness, some carbonate of ammonia in small portions, so that a double decomposition may take place, and the sulphuric acid be all driven off as sulphate of ammonia. In practice, however, this process is objectionable. It matters not how cautiously the carbonate of

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ammonia be added, it is dispersed with a kind of explosion which inevitably causes a loss of some of the finely powdered ore. When the crucible is allowed to cool before the addition of this volatile salt, and then reheated, this objection does not hold. Mitchell pulverized his carbonate of ammonia and added it in the proportion of one-tenth the entire amount of ore.* If, however, the assayer take care to heat the ore to *whiteness*, he may be certain that all the sulphuric acid will be expelled.

The reduction of the roasted ore is commonly effected by mixing it with three or four times its weight of black flux, introducing it into the same crucible in which the roasting was effected, covering it with about half an inch of glass of borax, and heating it in a wind furnace for about twenty minutes, in the manner described under the last head.

If the gangue be silicious and aluminous, the fusion is facilitated by the addition of lime to the flux, on the well-known general principle that a mixture of several earths is more fusible than a single one. If the usual quantity of ore (200 grains,) has been selected for an assay, it may be thoroughly mixed in a mortar with 50 grains of lime, 300 of dry carbonate of soda (i. e. carbonate of soda, recently heated to redness,) and from 20 to 40 grains of charcoal, according to the richness of the ore. Some assayers make it into a paste with oil and pack it in the crucible. The whole is now introduced into the fire and kept at a dull red heat for about fifteen minutes, or until the mass has ceased to swell

* Should the arsenic be present, it is advisable to mix the ore with charcoal. Some make it into a paste with sawdust and oil.

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and bubble. It is then covered with an earthen lid and heated to a full red approaching whiteness, for about the same length of time. It is not absolutely necessary to cover the crucible, but it is better to do so, as some bits of coal may get in, and cause a loss of copper which may adhere to their rough, irregular surface.

The crucible having cooled, is broken and the metallic button removed. Any adhering particles of slag are easily removed by a few gentle taps of the hammer. The surface of the button is now examined. If it is clean and bright, it may be inferred that the operation has been properly conducted. If, however, it be enveloped in a coating of gray brittle regulus, the assayer may know that his roasting has been imperfectly performed and that all the sulphur has not been expelled. The whole operation must then be repeated. It is always advisable to prepare two crucibles in the same manner, and to carry on the operation upon two samples of ore at the same time.

Various processes have been suggested, in order to avoid the trouble and delay of roasting. Mr. Maughan suggested an ignition in oxygen. He placed the substance in a porcelain tray which was introduced into a tube heated to redness, while a stream of oxygen gas was passed over it. The roasting was in this manner very rapidly accomplished, but the difficulty of decomposing the sulphates was not overcome.

"With nitre all the copper can be extracted, (from the sulphuret,) but with difficulty, and finding by repeated experiments, the quantity which produces the maximum result. Sulphuret of copper fused with a mixture

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of an alkaline carbonate and metallic iron, allows a certain quantity of copper to be set free; but this quantity never surpasses three-fourths of that contained. This maximum is obtained by using four parts of carbonate of soda, and thirty or forty per cent. of iron filings. The slag is black and homogenous.

"Copper pyrites is decomposed by the alkaline carbonates, but without the production of metallic copper. A black crystalline homogeneous slag is formed, which contains an alkaline sulphuret, a sulphuret of iron, sulphuret of copper and oxide of iron.

"With black flux a very fluid homogeneous crystalline slag is produced, the color of which is black with a metallic lustre, and in which not the smallest trace of metallic copper can be distinguished. The result is the same as the addition of iron, which is perfectly inert, and remains disseminated in the slag.

"Copper pyrites is readily attacked by nitre, and either copper or sulphuret of copper can be separated from it by means of this reagent. But in order to arrive at this result, it is necessary to guess the quantity of nitre; so that it is evidently not a good method of assay.

"It is necessary, in order that the slag be fluid, to add a little borax or an alkaline carbonate; so that the reduced metal may collect into one button. With one part of nitre, two of carbonate of soda and one of borax, pure copper pyrites gives from 36 to 46 per cent. of sulphuret; with double that quantity of nitre it gives thirty per cent. of metallic copper."

The above account of the behaviour of sulphureted

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copper ores, with different reagents, taken from Mitchell's Manual, throws light upon the various processes adopted. The success of the nitre assay depends upon its oxydating the sulphur in the mixed sulphides of the ore, forming sulphuric acid which combines with the potash. If the exact quantity of nitre, necessary for this oxydation, be hit upon, the maximum quantity of metallic copper is obtained.

Mr. Lewis Thompson has suggested a nitre process by which he proposes to get rid of the guesswork of the common fusion with nitre. He heats the finely powdered ore in a crucible to redness, and throws upon it excess of nitre. Powdered charcoal is then added so long as any deflagration takes place, and the heat is pushed to bright redness for a quarter of an hour.

The process is an imperfect one, on account of the continued presence of the sulphur. I have repeatedly tried it with all possible care, but have never been able to obtain satisfactory results. Two crucibles placed side by side in the same fire, and treated as nearly as possible in the same manner, have often given me different quantities of copper with this process.

It occurred to me to try cyanide of potassium as a desulphurating agent, since it is so efficient in reductions before the blow-pipe. My plan was to fuse a small quantity of cyanide in the crucible and when it was liquid, to add to it the finely powdered ore. A pasty mass resulted which when heated to redness swelled a good deal. Some more cyanide was then thrown in, as long as effervescence took place, and glass of borax placed on top. The heat was then pushed and the rest of the process

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conducted as before. I have obtained very good results in this way, but often, without apparent cause, I have failed.

At this point, I may remark that the dry assay cannot be relied on as giving a satisfactory determination of the copper contained in the ore, because, no matter how carefully the process may have been conducted, we can never be certain that the button contains copper only. It is valuable, however, as an indication of the manner in which the ore will behave in the furnaces, the proportionate yield of metal which may be expected, the nature of the slag, and a variety of similar matters which will readily occur to the mind of the practical man.

Sulphureted ores are commonly dissolved in aqua regia, as already described. Mr. Lewis Thompson uses chlorate of potash instead of nitric acid as an oxydizing agent. He pours upon 100 grains of the finely powdered ore concentrated hydrochloric acid, adds chlorate of potash in small portions, stirring all the while with a glass rod, until all action ceases. Should the residue be white, the operation may be regarded as completed; should it still remain dark, it is placed upon a sand-bath, and heated, additions of chlorate of potash being made from time to time, till all action has ceased. Should the residue still continue dark, it is to be roasted, and then treated in the same way again. The resulting solutions are mixed and precipitated with metallic iron.

It is necessary to conduct this operation under a hood, with a strong draught, or dangerous results may follow from the stifling vapors of euchloine which are abundantly evolved.

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Rivot's process may be adopted, when zinc in the form of sulphide, is not present. The ore having been reduced to an impalpable powder, (by porphyrization, if necessary,) is warmed with an alkaline liquor, and a stream of chlorine gas is passed through the whole. The copper and the other metals remain at the bottom as oxides, and the sulphur, arsenic and antimony are converted into acids which combine with the alkali to form salts.

The dry process above described may be performed directly upon the ores themselves when they are rich, but when they contain only 8 or 10 per cent., it is better to run them down first as regulus and then apply the process of roasting and fusion to that. If there is much earthy matter present, it interferes with the roasting, both by shielding portions of the ore from the oxydating influence of the air, and by furnishing bases with which the sulphur and newly formed sulphuric acid may combine. In the subsequent fusion also, they have a tendency to stiffen the slag and prevent the descent of the globules of metal. It is, therefore, better in these cases to adopt the fusion for regulus, as that enables us to obtain all the metal free from gangue, and the resulting sulphide can then be treated like a rich ore.

ASSAY OF ORES OF THE THIRD CLASS.

Ores of this kind require roasting, but it must be conducted with more care than the same process employed upon a simple sulphide, because they are far more fusible than the substances belonging to the last class. The metal obtained from the calcined ore requires a further

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operation, to be described under the next head, because it is a true alloy.

When the ore contains lead, especial care is necessary in roasting, as it so greatly increases the fusibility, that it is extremely difficult to expel all the arsenic and sulphur, without agglutinating the mass. It is better, indeed, in all cases, to obtain a regulus first and roast *that*, as the loss of sulphur and arsenic, during the process of fusion, renders the subsequent roasting more easy, by rendering the matt less fusible.

In an arsenide of copper, the first results of roasting are volatilization of a portion of arsenic and the formation of oxide and arseniate of copper and metallic copper. The arseniates and arsenides react on each other at a high heat, and arsenious acid is formed and vaporized. After the whole of the arsenide has been decomposed, there still remains behind some arsenic, in the form of arseniate of copper, which cannot be volatilized at a roasting heat. This is decomposed by adding finely powdered charcoal and heating to bright redness. The arseniates are reduced with the formation of arsenious acid which is expelled. In spite, however, of all this care, some arsenic will contaminate the button obtained in the subsequent fusion.

ASSAY OF SUBSTANCES OF THE FOURTH CLASS.

Alloys containing more oxydizable metals than copper are purified by a process called *refining*, which is in reality, a cupellation performed on copper.

For this purpose the operator must have a cupelling or assay furnace, with a strong draught, some cupels and tongs of a suitable construction. The furnace

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should have a strong draught, and be provided with a muffle in which the substance in the cupels is to be heated. The cupels are made of bone ash, and resemble little saucers with a flat bottom. For fuller information on the construction and management of the furnace and cupels, the reader is referred to the author's work on Dental Chemistry and Metallurgy.

The cupel having been introduced into the muffle and the whole being brought to a red heat, the button of copper is dropped into the cupel from a pair of tongs, when the muffle is closed to exclude the air and raise the temperature to the fusion point of copper. After the melting of the button, the muffle door is opened, and a little pure lead added to the alloy. Oxydation of the lead and the combined metals now begins; the button is agitated with a rapid rotary motion, and covered with an iridescent pellicle of oxide, which continually flows off and is absorbed by the cupel. When the process is about to terminate, the motion becomes more rapid and the colors of the pellicle brighten, till the button becomes suddenly solid, when the coating disappears entirely and the movement of the button ceases. This is called *brightening* or *fulguration*.

The cupel is now immediately removed. The button is covered with a fine crust of protoxide of copper which is not easily detached if allowed to cool slowly, but plunged while still hot into water, the oxide can be beaten off with a hammer. It is usually recommended to cover the button with about 7 per cent. of its weight of pure fused borax, finely powdered. The berate of copper thus formed, is very brittle and only slightly adherent to the metal, being easily detached by a single

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blow of the hammer. If the red hot button be plunged into a weak solution of phosphate of soda, the same results follow. The purity of the metal is known by its fine red color and its malleability.

It must be observed, however, that this method is not rigorously exact, because some copper is oxydated and sinks into the cupel along with the lead and other metals, and another portion is removed with the coating of oxide or borate of copper taken off from the refined button.

It is manifest, furthermore, that two cases may occur; the copper alloy may not contain lead, or it may be mixed with that metal. In the first case, a tenth part of lead is added till the copper be pure. To determine the true per centage of copper, Berthier recommends that one-eleventh of the weight of all the oxydizable metals including the lead added, and one-tenth of the weight of the borax thrown on the hot button should be added to that of the assay button obtained. It is manifest, that however near this estimate may be to the truth, and however well it may answer for practical purposes, it has no claim to be considered scientifically exact, because the loss depends not only upon the nature of the oxydizable metals present, but also upon the heat to which the button has been subjected.

In the second case, or when the copper alloy contains lead, that metal may exist in three different conditions; there may be either too little for the purposes of the refiner, or just enough, or too much. When there is too little, lead must be added by tenths till the button is pure. When there is just enough, there is of course, nothing to be done but to proceed with the cupellation.

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When there is too much, a weighed quantity of pure copper must be added, and the usual allowances made in estimating the button.

This process may be conducted without the inconvenience of these numerous suppositions, by operating at once upon two samples, one of pure copper, the other of the alloy to be examined. For this purpose, two cupels are placed side by side in the same muffle, and when heated sufficiently, 4 parts of pure lead are introduced into each. As soon as the metal is melted, 1 part of pure copper is introduced into one, and 1 part of the alloy under examination into the other.

The refining is conducted in the usual manner, and when the resulting buttons are weighed, it will be found that that obtained from the pure copper is the heavier. By adding the loss of the fine copper to the weight of the button refined from the alloy, the quantity of pure copper contained in the last is determined, since we have every reason to suppose that the loss of copper in both assays is precisely the same.

In operating upon cupriferous leads, 1 part of pure copper is treated with 4 parts of pure lead in the cupel, and with 4 parts of the cupriferous lead in the other. The second operation gives more copper than the former, and the difference is the proportion of copper in the cupriferous lead.

The advantage of this method is that it furnishes good data whereupon to compute the probable result of metallurgic operations in such alloys, on the great scale. The process is, however, not applicable to alloys containing much zinc or tin. Indeed, in all cases, the humid analysis furnishes by far the most exact results.

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CHAPTER III.

MINES AND MINING.

It is necessary, in order to understand the character of mineral deposits, to have some distinct ideas of the general principles of geology. We shall, therefore, recall to our readers' recollection a few of the simpler facts of that science, before proceeding to give an account of mines or mining operations.

The earth, upon which we live, is generally believed to be a mass of fused matter which has cooled off upon the surface. The centre is supposed to be still in a state of igneous fusion,* while the cooled surface forms a crust upon which all the substances which maintain our present existence are found. To this crust the observations of geologists have been confined, and they have been able to lay down certain definite laws for the guidance

* There are many phenomena which support this opinion, and which, indeed, seem inexplicable upon any other theory. Thus, in mines and artesian wells, it has been observed that a depth is soon reached, which the ordinary surface changes of temperature no longer affect, and that, as we descend, we find a heat continually increasing. This increase is found to be one degree of Fahrenheit's thermometer for every 55½ feet, so that at less than 1–700 of the earth's radius a temperature of 3600° will be obtained. At 1–50 of the distance from the centre, therefore, we may conclude that every thing is in a state of fusion.

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of practical men, which are as positive as any other rules deduced from the study of nature.

The most superficial knowledge is sufficient to determine the fact that this crust, of which we have been speaking, is not a homogeneous mass, but is composed of quite a variety of substances commonly known as minerals. These are found in various positions and in various degrees of aggregation, and to their masses geologists have applied the generic term, *rock*.

Every one must have noticed that some rocks split up readily into layers, while others only afford irregular masses when broken, and that the former lie in regular strata superimposed upon one another, while the latter present no indication of such an arrangement. The former are called *stratified*, the latter *non-stratified* or *crystalline* rocks. The latter presenting all the appearances of having cooled from a state of fusion, have received the additional name of *Plutonian* or *igneous rocks*, while the former, resembling the deposits now taking place from turbid water, are called also *Neptunian* or *sedimentary rocks*. When these have come in direct contact with the igneous rocks, still fluid, the heat of the fused mass has produced a change in the character of the sedimentary rock, and without destroying its stratification has rendered it crystalline. The deposits thus altered have received the name of *metamorphic rocks*.

If the earth had never been subject to violent convulsions, we might imagine the layers of these sedimentary and metamorphic rocks surrounding it in segments of concentric spheres, like the coats of an onion. But in reality, the surface has been disturbed both before and

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after the deposition of these rocks. We have, therefore, numerous irregularities in the position of the layers. Great masses of crystalline rock, during those terrible convulsions which characterized the early ages of the world, have been thrown violently up from the fused centre, upheaving the superficial strata. Sometimes this upheaval seems to have been in the form of a great wave, rolling under a wide area, so that half a continent has been lifted up without greatly disturbing its surface. At others, the melted matter has been forced up in a single circumscribed jet; has burst through the crust turning up its layers, and protruding above in high hills or mountain masses. The traveler, therefore, as he passes over the broken edges, in approaching the centre of upheaval, goes over them in the order of succession from above downward, but after crossing the ridge, finds them arranged in the reverse order. Now it is evident, that if water should have swept over these displaced strata, with great violence, it would have removed the surface, and worn them irregularly, in accordance with their relative hardness, forming hills and valleys of *denudation*. Again, should a sea have rolled for any time over the upturned edges of the broken rocks, stratification would again have taken place, and as this would necessarily form an angle with the original direction of the layers, we would have what is called *unconformable stratification*. These may again be worn by water, and in the new hollows, still later deposits may occur, so that it would be easy to make gross errors in regard to the age of rocks, if we had not some guide to show us the order of the deposits. We find an index of this in a

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careful study of the succession of the strata, but chiefly in the fossils which the different formations contain.

In the foregoing remarks we have spoken in accordance with prevailing geological opinions, to which it is well now to give a more formal expression. In the cooling of the crust of the earth, we take it for granted that there must have been much contraction. This contraction must of course compress the central fluid, and being unequally acted on, it must break out at the point of least resistance. Other causes besides this contraction, may act to produce the occasional escape of the central liquid. Through the rents, however made, fused matter may be extruded, and in this manner, many have accounted for the existence of metallic veins, and for the greater certainty of continued value in the regular veins. This, however, is a subject to which we shall presently recur.

The first geological division of rocks was into *primary* or *primitive* and *secondary*. The term *primitive* or *primary* was applied indiscriminately to all crystalline rocks, while *secondary* was the title of all the stratified rocks. The facts of the science, however, began soon to accumulate so rapidly, that they could no longer be crowded into such narrow limits. The *secondary* rocks were, therefore, divided into *transition*, *secondary* and *tertiary*. The first of these terms was applied to the lower stratified rocks, which, though sedimentary, nevertheless, contain abundance of crystalline minerals. The more recent deposits were called *tertiary*, and everything between the two retained the old name of *secondary*. The term *primary* is now used very loosely, some writers

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confining it strictly to *azoic rocks*, or those without organic remains, while others extend it to the *palæozoic* series, or those in which we find the earliest traces of organized forms. Indeed, this whole system of nomenclature is gradually passing away, but as it is still partially employed we shall presently give a table of it. It will first, however, be necessary to explain briefly the terms applied to the principal varieties of rock. Those who wish more minute information, must have recourse to works on mineralogy and geology.

Granite is a mixture of feldspar, quartz and mica, in varying proportions. When studded with crystals of feldspar, it is called *porphyritic granite*. If hornblende takes the place of mica, the resulting rock is *sienite*.

Porphyry is a mass of feldspar containing crystals of the same mineral.

Gneiss is only a stratified granite, resulting from the uniform direction of the mica.

Trachytes are the products of old volcanos, which have sometimes flowed out as lava, and sometimes have merely formed a pasty mass. Like porphyry, they are composed of a feldspar base and often contain imbedded crystals of that mineral.

Basalt is the eruption of more recent volcanos than those which give rise to trachyte. It has a tendency to separate into hexagonal prisms of great size, composed of segments fitting into one another by means of a rounded head adapted to a saucer-like depression. Mineralogically, it consists of feldspar and augite, and often contains distinct crystals of one or both of these minerals.

Trap or *greenstone* is a dark, heavy rock, containing

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feldspar and hornblende, and is either crystalline or compact.

Lavas are the eruptions of modern volcanos, and are usually formed in their strata on the sides of the mountains whence they have issued.

Schists or *schistose* minerals are those which split easily in their layers.

Sand is a term usually applied to loose particles of quartz. Should they be agglutinated by a cement, the resulting rock is a *sandstone.*

Calcareous rocks are composed of carbonate of lime, mixed sometimes with carbonate of magnesia. In the latter case, the rock is called *dolomite.* Marble, Iceland spar, chalk and limestone are the common species of this class of rocks.

The table we have selected is that of Sir H. T. De la Beche, which shows the order of succession of the strata of Western Europe.

UPPER STRATIFIED, OR FOSSILIFEROUS ROCK.

I. TERTIARY, OR CAINOZOIC.
II. SECONDARY, OR MESOZOIC.
III. PRIMARY, OR PALÆOZOIC.

I. *Tertiary, or Cainozoic.*

A. Upper Tertiary, { *a.* Mineral accumulations of the present time. *b.* Pleistocene.* *c.* Pleiocene.
B. Middle Tertiary, Miocene.
C. Lower Tertiary, Eocene.

* These terms are combinations of Greek comparatives and superlatives, with a word denoting *recent.* Thus Pleistocene indicates those layers which have the *greatest* number of recent species. Pleiocene those which have *more* than the strata below them, Miocene, those which have fewer, and Eocene (dawn of recent,) those in which the existing types just begin to show themselves.

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II. *Secondary, or Mesozoic.*

- A. Cretaceous Group,
  - *a.* Chalk of Mæstricht and Denmark.
  - *b.* Ordinary chalk, with and without flints.
  - *c.* Meerschaum beds, or upper green sand.
  - *d.* Gault.
  - *e.* Shanklin sands, vecten, neocomian, or lower green sand.
- B. Marine equivalents of
  - *a.* Wealden clay,
  - *b.* Hastings sands,
  - *c.* Purbeck series,

  } Organic remains in these are of a fluviatile, lacustrine or estuary character;
- C. Jurassic or Oolitic Group,
  - *a.* Portland oolite or limestone.
  - *c.* Portland sands
  - *d.* Kimmeridge clay.
  - *e.* Coral rag and its accompanying grits.
  - *f.* Oxford clay, with Kelloway's rock.
  - *g.* Cornbrash.
  - *h.* Forest marble and Bath oolite.
  - *i.* Fuller's earth, clay and limestone.
  - *k.* Inferior oolite and its sands.
  - *l.* Lias, upper and lower, with its intermediate marlstone.
- D. Triassic Group,
  - *a.* Variegated marls, Marnes Irisées, Keuper.
  - *b.* Muschelkalk.
  - *c.* Red sandstone, Grés Bigarré, Bunter sandstein.

III. Primary or Palæozoic.

- A. Permian group.
  - *a.* Zechstein, dolomitic, or magnesian limestone.
  - *b.* Rothe todte liegende, lower new red conglomerate and sandstone, grès rouge.
- B. Marine equivalents of
  - *a.* Coal measures, terrain Houiller, Stein Kohlen Gebirge.
- C. Carboniferous limestone group.
  - *a.* Carboniferous and mountain limestone, with its coal, sandstone, and shale beds, in some districts. Calcaire carbonifére. Berg kalk.
  - *b.* Carboniferous slates and yellow sandstone.
- D. Devonian group.
  - Various modifications of the Old Red Sandstone series.
- E. Silurian group.
  - *a.* Upper: Ludlow rocks, Wenlock shale and limestone, Woolhope limestone.
  - *b.* Middle: Caradoc sandstone and conglomerate.
  - *c.* Lower: Llandeilo and Bala beds.

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F. Cambrian group. — Barmouth sandstones, Penrhyn slates, &c. Various rocks subjacent to the Silurian series in Wales and Ireland, and above the mica and chlorite slates, quartz, and other rocks of Anglesea and part of Caernarvonshire. Unknown: probably primitive.

MINERAL VEINS.

The metallic products of the earth are found in a great variety of situations. These have been classified under the following heads:

I. Superficial or Alluvial.

II. Stratified.
- *a.* Constituting the mass of a bed or stratified deposit.
- *b.* Disseminated through sedimentary rocks.
- *c.* Originally deposited from aqueous solution, but since metamorphosed.

III. Unstratified Mineral Veins.
- *a.* Masses of eruptive origin. } Irregular
- *b.* Disseminated in eruptive rocks. } Irregular
- *c.* Stockwerke deposits. } Irregular
- *d.* Contact deposits. } Irregular
- *e.* Fahlbands. } Irregular
- *f.* Segregated veins. } Regular.
- *g.* Gash veins. } Regular.
- *h.* True or fissure veins. } Regular.

I. *Superficial or Alluvial Deposits.* All the alluvium that we have upon the surface of the earth is the result of the wearing away of older formations. If a mass of rock, subjected to the wasting action of the water, frost, and atmospheric influences, should contain metallic substances, we must expect to find them mixed up with the sand and gravel which are formed from its ruins. These alluvial districts are often of great extent, and though the working of them cannot be properly called mining, they furnish large amounts of the most valuable metals. Most of the gold, much of the tin,

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and all the platinum of commerce, comes from such workings.

The position of these different metals varies considerably. The alluvial gold is usually found at all depths of the soil in which it occurs. Tin, on the contrary, generally lies below the surface, and is covered in by a greater or less depth of gravel, sand, or clay, and sometimes peat. In order to get at the tin gravel, it is necessary first to remove this overlying earth, when the metalliferous pebbles will be found, generally lying upon the primitive rock.

The amount yielded by these washings is very great. Every one knows that the majority of the gold in California, comes from the surface washings. All the Australian, and nearly all the Russian gold, so far, has been produced in that way. When we know that California, in 1853, produced 250,000 pounds troy of the precious metal, Australia 210,000, and Russia 64,000, we see the immense value of these superficial deposits. Of platina, during her period of greatest mining activity, Russia produced nearly five thousand pounds annually. Of tin, Banca alone produces from her alluvial deposits, 5,000 tons a year.

Stratified Beds. Under this head are included all metallic deposits which have evidently been formed at the same time with the sedimentary rocks in which they occur. The best illustration of this method of occurrence of metalliferous beds is to be found in the seams of iron ore interstratified with the coal in this country and in Great Britain. When the more valuable metals are found in such layers, the deposits are usually

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regarded with suspicion. They rarely increase in richness as they descend, and they cannot be expected to "hold out" sufficiently to justify any large investment for their development. There are exceptions to this rule, however, as we shall see, when we come to speak of the Mansfield schists.

Unstratified Deposits. Under this head, we find the most valuable collections of metallic ores. They are divided in our tables under two heads, *regular and irregular deposits.*

Irregular Deposits. 1. *Eruptive Masses.* These are aggregations of rock resembling the surrounding non-metalliferous rocks. The ores which most frequently occur in this manner are the oxides of iron, which seem to have been thrown up at the same time with the igneous rocks in which they are found. The great iron-ridges of the West are good examples of this form of metallic deposit. They either form ridges, parallel with those of the neighboring strata, or assume the form of rounded masses, which have evidently burst up from below, fracturing the crust upon the surface, and fusing or otherwise changing the strata in immediate contact with them.

2. *Disseminated in eruptive rocks.* It often happens that in a great upheaval of trap, we find numerous metallic particles, widely diffused through the entire mass of rocks. In this manner platina sometimes occurs. Magnetic iron is found in such abundance diffused through the trap at Tabey, in Sweden, that it can be worked to advantage. At Geyer, in Saxony, small thread-like veins, and minute particles of tin, are diffused through a great mass of granite.

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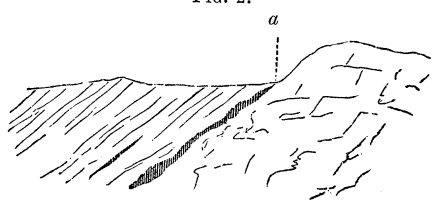
FIG. 1.*

STOCKWERKE.

3. *Stockwerke.* A stockwerk is a series of small veins intersecting one another and ramifying through a mass of rock, which often contains also minute particles disseminated through it. The name has been given to them because they are worked in different stages or storeys, one above another. For the same reason, the English call them *floors*. Tin occurs in this manner, both in Cornwall and in Saxony.

FIG. 2.



CONTACT DEPOSIT.

a Deposit of ore between two formations.

4. *Contact Deposits.* These metalliferous beds are formed, as their name implies, at the point of contact of two formations dissimilar in their geological and mineralogical character. When a mass of eruptive rock, (trap, for example,) breaks through another formation,

* This and the following illustrations are taken from Whitney's "Metallic Wealth of the United States."

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modifying its mineral contents, a line of ore will often be found separating the two kinds of rock. If not exactly upon the dividing line, it occurs at no great distance from it, and preserves a general parallelism with it. Or metalliferous minerals may be found lying between two successive overflows of igneous rock, or diffused through both of them in the neighborhood of the separating surface. Thus, the iron ores of the Hartz follow the contact-planes of the trap and the uplifted slates; and those of the Vosges surround a central nucleus of porphyry, and line all the cavities of the fracture produced by the upheaval. The copper ores of Monte Catini, in Tuscany, are developed along the line of outcrop of the gabbro, a rock resulting from the metamorphic action of serpentine upon the cretaceous strata.

5. *Fahlbands.* These are best developed in Norway, at the silver mines of Kongsberg.* There, in the crystalline states, occur parallel belts of rock of very considerable length and breadth, impregnated with the sulphurets of iron, copper, and zinc, with a little lead and silver. These are disseminated through the rock in such minute portions as to be hardly visible, and only to be recognized by their tendency to decompose, and thus to give the rock a rotten appearance. To this they owe the name "fahlband," or "rotten belt," the word *fahl* being a corruption of *faul*, the miners term for a rotten rock.

These belts at Kongsberg exhibit the general charac-

* They have been traced for several miles. The greatest breadth of any one of them is a thousand feet.

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ter of the rest of the strata in the vicinity, having the same direction and inclination, and being, like them, schistose. The quantity of metallic matter contained in them is generally small, and rarely pays for working. They are, however, traversed by true veins, containing silver ores, and these are only productive where they pass through the fahlband. The chief mining value, therefore, of these strata, results from their enriching influence on the true veins which intersect them. Even with these, the mining here is very expensive.

Deposits of the kind we have just been describing, under these five heads, while often developed to such an extent as to be valuable, are generally inferior to true veins. They are not so deep, have gangues which are hardly to be distinguished from the adjoining rocks, and often are destitute of any proper vein-stone. As a general rule, they cannot be worked to the same advantage as the regular deposits, since the miner can rarely have any security that they will hold out sufficiently to justify the necessary expenditure.

Regular Deposits. These are classified under three different forms, which are not always easily distinguished from one another. Surface examination is often insufficient to enable the most experienced observer to decide whether a true vein exists, and an exploration of some depth below the surface is absolutely necessary to settle the question.

Werner defines veins as "mineral repositories of a flat or tabular shape, which traverse the strata without regard to stratification, having the appearance of rents or fissures formed in the rocks, and afterwards filled up

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with mineral matter differing more or less from the rocks themselves." Whitney objects to this definition as excluding many veins which do not traverse, but run parallel with the strata, and others which occur in unstratified rocks. His definition is, "an aggregation of mineral matter of indefinite length and breadth, and comparatively small thickness, differing in character from, and posterior in formation to, the rocks which enclose it." Both these definitions include veins which do not contain metal.

Weissenbach divides true veins into six different classes.

1. *Veins of sedimentary origin.* If a fissure should exist in a rock upon which a new deposit of a sedimentary character was taking place, it must, of course, be filled by the sedimentary matter, which will be stratified in it just as it is on the general surface of the rock.

2. *Veins of attrition.* These are fissures filled with matter introduced by purely mechanical means, such as the falling of fragments of wall rock from above, or friction of their sides upon one another. Many ore-bearing veins exhibit phenomena of this kind.

3. *Veins of infiltration, or stalactitic veins.* These result from the filling of fissures by incrustation of the sides with calcareous matter deposited from water, precisely in the same manner in which stalactites are formed in caverns.

4. *Plutonic veins.* These are fissures filled with mineral matter injected from beneath, or pressed upwards while in a plastic state.

5. *Segregated veins.*

6. *Metalliferous veins, proper.*

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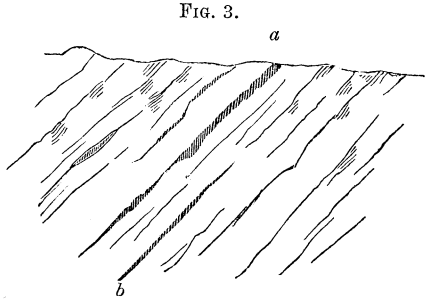
Before going further in the description of true veins, we pause to explain certain technical terms in common use among miners. Veins, as we have already said, may be barren of metal; hence, the word *vein* is a generic term. Those which contain ores are called *lodes*, and those which are not productive, and are not in the usual direction of the lodes of a district, are termed *cross courses*. The rock in which the lode is found is called the *country*. The dip or inclination of the vein towards the horizon, is its *hade*, *slope*, or *underlie*, and its superficial length is its *run*, *bearing*, or *direction*. *Strings* are small filaments into which the vein splits, and these, when very small, are called *threads*. The two sides of the cavity, which contain the lode, are called *walls;* and if the vein has a considerable inclination, its upper boundary is called the *hanging wall*, and its lower, the *foot wall*.

We now resume the consideration of the classes of regular deposits.

FIG. 3.



SEGREGATED VEINS.

a Segregated mass of ore cropping out at the surface. *b* Parallel layer not extending upward so far.

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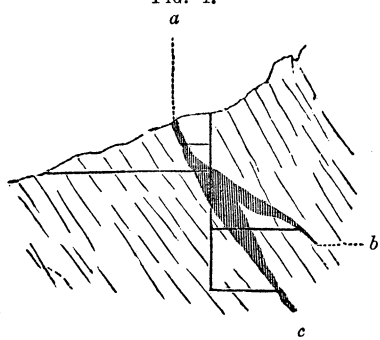
1. *Segregated veins.* These are veins which have a crystalline structure, or a gangue differing from the adjacent rocks, but which do not appear to occupy a previously existing fissure. They seem to have been gradually separated by chemical action from the surrounding formation; hence their name, segregated veins. They differ from true veins in their relation to the adjacent stratification. They lie parallel with the cleavage of the surrounding rocks. The downward extent varies greatly, and the mass generally thins out, and entirely disappears at a greater or less distance from the surface. In the Rammelsberg, one of the

FIG. 4.



SECTION OF THE RAMMELSBERG.

a c Principal mass of ore lying in the direction of the argillaceous shales. *b* Branch four hundred feet deep, dipping further from the perpendicular.

Hartz mountains, a famous mine of this character occurs. The main mass of ore lies in the direction of the argillaceous slates of which the mountain is composed. At the depth of about four hundred feet, it sends off a branch which crosses the dip of the slates at an acute

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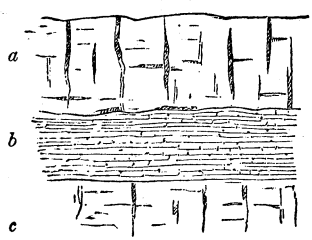
angle. The greatest thickness of the mass is more than one hundred and fifty feet, and its length about nineteen hundred. As it descends, however, it grows smaller. Thus, at eight hundred and fifty feet, it has contracted to twenty feet in thickness and seven hundred and fifty in length. It has no proper vein-stone, but is a mass of sulphurets of iron, zinc, lead, and copper, and almost entirely destitute of gangue. The veins of gold quartz are usually of this character, occurring in belts which dip with the stratification.

These deposits cannot be relied upon as true veins. They are almost always richest at the surface, and are liable to thin out, or even entirely to disappear. The ore is distributed through them with no regularity, occurring usually in nests and pockets, arranged in a general linear direction, and connected by mere threads of ore or barren vein-stone.

FIG. 5.



GASH VEINS.

a Upper series of veins. *b* Stratum cutting off the upper series entirely from *c*, the lower series of veins, which are independent fissures.

2. *Gash veins.* These veins occupy pre-existing fissures, which are not attended by any considerable breaking up of the strata. When there is a marked

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difference in the character of the rocks which make up any particular series, the fissures are usually confined to one member of the series, and disappear on passing to the next. If the same rock occurs again on the other side of the interpolated mass, the veins may be found in it. Lateral branches are often found in connection with the main fissures, and usually at right angles to them.

The origin of this class of fissures has been attributed to the shrinkage of the rocks, either during cooling, or in consequence of a subsequent exposure to long-continued heat. Thus, mineral contents may have been deposited as sediment, or segregated from the mass of the rock. They differ from true veins, in not showing such distinct selvages, and in the less decidedly crystalline character of their vein-stones. They are generally found in those sedimentary rocks which have undergone but little change, and still retain the original lines of stratification. They are still less reliable than segregated veins, but their number often makes up for their limited extent, so that, while any individual vein cannot be expected to hold out, the region in which they occur, may, for a time, furnish a large amount of ore.

3. *True veins.* These are fissures in the crust of the earth, of indefinite length and depth, which have been subsequently filled with mineral matter. As they are believed to have originated in a fracture of the strata caused by the action of a powerful force far below, they may be expected to extend indefinitely downward. Experience so far verifies this opinion that no well developed and well defined vein has yet been found termina-

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ting entirely at any depth which has been reached, while nothing is more common than a total disappearance of the other forms of deposits which we have described.

The length of veins upon the surface varies greatly. Some have been traced for miles, and differ, as to their metallic contents, in different parts of their course, some points being entirely barren, while others are well charged with ore. As a general rule, the longer the vein, the more liable is it to prove productive somewhere. Some of the great veins in Mexico have been followed more than six miles, and opened and worked in many places. The length and breadth of a vein have no necessary relation. The width is of course irregular, because when the fracture took place the rocks were not only torn apart, but also uplifted, so that one side of the crack has slid upon the other, making a fissure altogether devoid of parallelism between its two faces. If this notion of the previous fracturing of the surface be correct, we should expect to find a concentration of veins in certain regions of the earth, for a great upheaval which should fracture the crust in one place, would be likely to cause numerous cracks all about the centre of the greatest force. It certainly increases the probability of the correctness of the theory, to discover, as we do, the very limited and scattered districts which have so far produced the metals in general use among men.

The vein is not a mass of ore exclusively. The greater portion of it is occupied by some rock, different from the surrounding strata, which is known as the *vein-stone* or *gangue*. Quartz is the most common mineral found in this position. It occurs in a variety of forms,

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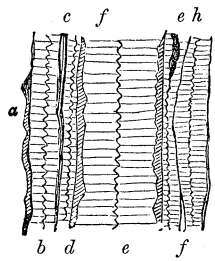
usually highly crystalline, especially in the "vugs," or cavities, of the vein. Each mineral district appears to have vein-stones peculiar to itself.

FIG. 6.



PART OF A LODE AT WHEEL JULIA, NEAR BINNER DOWNS, CORNWALL.

a Bisulphuret of copper and sulphuret of zinc. *b* Comb of quartz. *c* Wall of indurated argillaceous matter. *d* Comb of quartz. *e* Large comb of quartz, with blende and copper ores *f* on both sides. *g* Cavity or vug, in another comb of quartz. *h* More solid comb of quartz.

The minerals in a well defined lode often form a series of plates, parallel to the walls of the lode, and containing crystals set at right angles to them. These crystalline layers are called *combs*, and their faces meet and interlock with one another. Sometimes these are arranged in perfect symmetry, the same substances crystallizing with great regularity at corresponding distances on each side of the central mass.

In addition to the true vein-stones, the lode often contains fragments of the adjacent strata, which appear to have been introduced mechanically. These may be in numerous minute pieces, so as to give the gangue a brecciated character, or they may be in large masses. When one of the latter occurs, it is called a "horse," and the vein is said to "take a horse." The fissure

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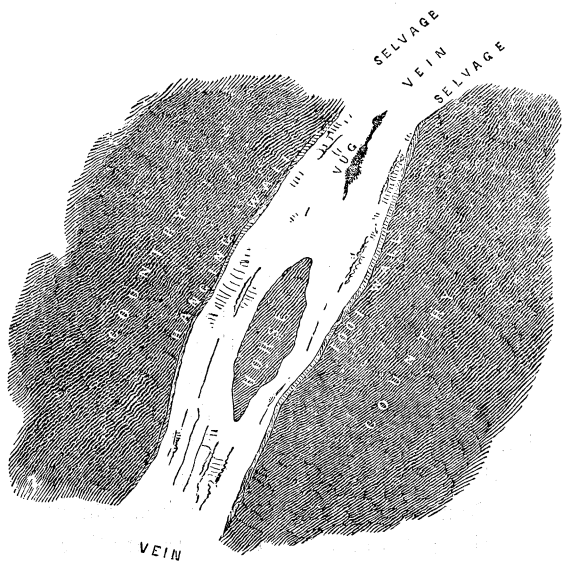
has often numerous offshoots, or supplementary fissures, branching from it; these are called "droppers," when they leave the vein, and when they concentrate, or fall into it again, they are named "feeders." Their direction and appearance are important guides to the miner. The vein-fissure is sometimes abruptly contracted, and then it is said to be "nipped."

FIG. 7.



TRAVERSE SECTION OF A VEIN.

The mass of vein-stone is usually separated from the wall by thin bands of clay, or similar soft substance, which are called "selvages." By preventing too close adhesion to the rock, they facilitate the removal of the

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contents of the vein. The walls are often smooth and grooved as though the lode had rubbed against them. These surfaces are called "slickensides."

Few veins are so uniformly rich in ore as to pay for the entire removal of their contents. It is customary, therefore, to confine the operations to the rich portions of the vein, leaving the poor undisturbed. The waste, unproductive matter brought to the surface, is called *deads* or *attle*. The rich bunches are very irregular in their occurrence, and the chances of finding them in any particular spot can only be estimated after a thorough examination of the system of lodes in the district under consideration. One kind of rock usually is richer than any other, and this presents, of course, the greatest inducements for a liberal expenditure of time and money. Where there are numerous parallel veins, the *run of the courses of ore*, or the relation of the rich masses to the entire vein, will usually be found to be similar in all the lodes. When, therefore, one has been properly opened and explored, it serves as a guide to all the rest. It requires, however, no little experience to decide upon the characters which justify working, and even then, the longest acquaintance with these subjects will often serve to mislead the miner who attempts to apply the rules of one district to another mining region.

The irregularities of the fissures, of course, involve the practical miner in numerous difficulties. A vein has been known to dip parallel with the strata, and then to be shifted to a plane twenty or thirty feet distance, without any dislocation of the surrounding rock. In

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such a case, a fissure may connect the two fragments of the vein, and yet be so small as to escape attention. At Holzappel, in Baden, there is such a shifted vein, in which the fissure, though cut by a level, was entirely overlooked, and the lode was not discovered till after a shaft had been sunk from the level, in the other portion of the vein. A true vein also may for some distance coincide with the dip of the strata, and may send out offshoots which follow the planes of cleavage, and yet the main fissure in the rest of its course may cut the different layers across. In such a case, it will be necessary to cut the lode for some distance, in order to ascertain whether it be a genuine fissure-vein, and whether the branches parallel to the stratification, have not been opened along the line of easiest fracture.

After the first set of fissures had been made and filled up, there was no reason why a new set should not occur, since the crust of the earth was still subject to the same influence. There is abundant evidence of such subsequent fractures, in the numerous secondary veins which cross the older lodes, and "heave" them to one side or the other. There are even examples of a tertiary set of fissures crossing both the former. We have already said that these veins, when destitute of ore, are called "cross-courses;" when they contain ore, they receive the name of "contra-lodes."* Cornwall contains several systems of fissures, and it is remarkable that those of the same age are usually parallel, and contain the

* These crossings of different sets of veins are usually considered favorable indications of rich veins, especially at the point of contact.

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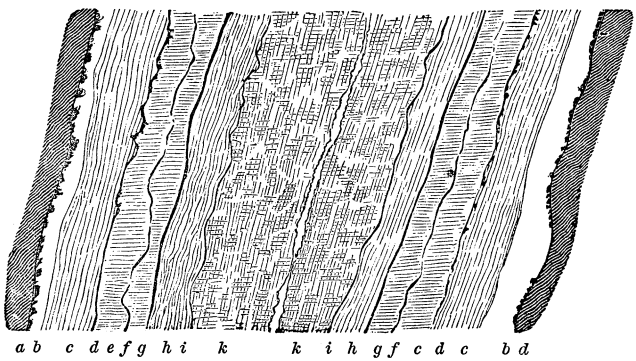
same varieties of ores and veinstones. In the Hartz there are two principal directions of fracture. In the Freiberg districts, these intersections are more numer-

FIG. 8.



FRAGMENTS OF THE DREI PRINZEN SPAT VEIN, NEAR FREIBERG.

a Blende. *b* Quartz. c Fluor Spar. *d* Blende. *e* Heavy Spar. *f* Sulphuret of Iron. *g* Heavy Spar. *h* Heavy Spar. *i* Sulphuret of Iron. *k* Calcareous Spar.

ous than anywhere else, more than nine hundred different veins having been recognized in the space of forty or fifty square miles.

In this country no such complicated system has yet been discovered. In the Lake Superior region, the veins of any limited district are usually parallel. Some movement of the planes of stratification upon one another has taken place, which has shifted the veins for a few feet in the direction of the slide.

One of the most commonly received opinions as to the method in which metallic veins have been formed, is that which attributes them to the injection of molten matter from below into the previously formed fissures.

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This may be true of a limited number of veins, those for instance, which have igneous veinstones, but it cannot be used to explain the production of the majority of metalliferous lodes. The difference in the value of the vein in different members of the geological series in which it occurs, appears to be a formidable objection to this theory. In the same light, also, must we regard the usually unbroken condition of the walls of the cavities which contain the lodes.

Another theory accounts for the formation of veins by sublimation from below and condensation in the fissures. There are facts which accord very well with this opinion. Thus, at Nagyàg, in Transylvania, metallic arsenic is deposited upon those faces of crystals of manganese-spar which have been turned downwards. There are, however, a great number of phenomena which refuse to adapt themselves to any such notion. The variation in the character of lodes in different rocks is as little explicable upon this hypothesis as upon that last noticed. The presence of non-volatile matter in veins has also been objected, but it is not easy to decide what is, and what is not volatile, at the high temperature of the earth's centre. The veins to which this theory is most applicable, are those of mercury.

At present, the views of the advocates of *lateral secretion* are most generally received. Those who hold these opinions, believe that the mineral and metalliferous particles have been separated from the surrounding rocks in a state of solution, and have been deposited within the vein by the action of electro-chemical forces. It is certainly in favor of this theory, that the majority of

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the veinstones, such as calcareous spar, quartz, &c., are now generally believed to have been deposited from aqueous solution, and certainly cannot have been sublimed by igneous action. The ores may also be deposited in the same way. Galena has been made artificially, in the laboratory of the chemist, from aqueous solution by double decomposition. Sulphuret of iron is a common product of the contact of ferruginous waters with decaying organic matter. Murchison has shown that the copper ores of the Permian strata, in Russia, must have been formed in the same way, since they are accumulated round the remains of the stems and branches of plants.

The fissures opened deep in the crust of the earth, may be supposed to have been filled with water holding mineral matter in solution. Passing through the different strata, these solutions would be differently acted upon in accordance with the varying chemical constitution of the rocks. If the water were acidulated, it would act upon the metallic particles with which it came in contact. It is easy to see how, on this hypothesis, a vein might be richer in certain rocks than in others. Either the rock might contain more metallic substances, or it might act more readily upon those in solution in vein-fissures. That some action has taken place in the surrounding strata, is evident from their alteration in the neighborhood of the lode. They are either decomposed and rotten, or they are more impregnated with silicious matter. In the latter case, the flinty masses are called by the Cornish miners the *capels* of the lode.

The existence of electric currents in veins has been

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established by the testimony of several independent observers. They are supposed to originate in the lode and to have no connection with the great magnetic circles of the earth.

Nearly all veins are characterized near their surface by evidences of atmospheric or other chemical action. The surface ores vary from those which we find below, in being far more highly oxydized. Thus, if the mass of the vein contain sulphurets, we find the surface ores almost exclusively carbonates, silicates and other oxy-salts. In many copper veins, the copper has almost wholly disappeared, the sulphurets having been oxydated to sulphates, which, being soluble in water, have washed out, leaving a porous iron ore, or a peculiar rotten, weathered, stained quartz upon the surface. This is called by the Germans the "iron hat," and by the Cornish miners "gossan." The depth to which these alterations extend is very variable. Sometimes it is confined to the surface, the sulphurets remaining undecomposed up to the soil. Usually it reaches to a depth of a hundred feet, and it has been known to be still quite evident at three hundred feet below the surface.

To recapitulate the practical points, we may say that true fissure-veins are deep and do not run out or sensibly diminish in contents of ore at any depth which has yet been reached; while segregated and gash veins, and the various irregular deposits, though often very rich as far as they go, cannot be relied on as having the same permanence with a true vein.

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MINING OPERATIONS.

The presence of valuable veins of ore is recognized by *surface indications*, or by a series of systematic explorations. The former can rarely do more than establish a vague probability, and those which are still relied upon in some places, are altogether futile. Such are the heat of thermal springs, gratuitously attributed to the decomposition of pyrites; the impregnation of running water with metallic salts which may have come from some very remote point. If, however, a small rill, in a rocky region, should be discovered to contain at its source, metallic salts, it will generally be safe to infer the presence of ores somewhere in its immediate neighborhood. Streams impregnated with sulphates of copper and iron, have been known to issue from rocks containing copper pyrites, one of the most valuable ores of that metal. It must be borne in mind, however, that this ore may be diffused through the strata, and not concentrated in a vein, in which case, it will rarely pay for the labor necessary to be expended upon it. Springs, heavily charged with ferruginous matters, are no bad indications of the neighborhood of workable beds of iron ore, especially in alluvial and carboniferous regions.

A knowledge of geology is essential to any one who would form an opinion as to the value of a country for mining purposes. It enables him at once to exclude a large number of minerals, which could not be found in the regions under consideration. It saves him the trouble of digging for substances which there is no probability of finding, and enables him to seek for infor-

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mation where nature has been at the trouble of disclosing it to him.

A vein cannot be expected to escape the ordinary weathering and decomposing influences of the atmosphere, the rain, and the frost. The surface overlying it will probably be covered with the fragments which have been detached from it. Thus, in a chrome-iron region, the position of the vein is indicated by the presence of angular fragments of the gangue, stained of a peculiar yellowish green. In the Hartz mountains, the *iron hat* to which we have already alluded, has been found to overlie valuable veins of lead and silver. The weathered and decomposed quartz, and the porous iron ore, called *gossan*, is in many regions regarded as a valuable surface indication of copper. These indications will be rendered more certain by a careful study of the general character of the veins in a district. Thus, for example, if in any region, ores of copper should be found largely intermingled with magnetic iron, a defined band of fragments of the latter ore lying upon the surface, would afford sufficient inducement for exploration below. When the ores of a vein lie high, they will also be found distributed over the surface. Thus the presence of stains of carbonate or silicate of copper, in fragments of rock differing from the general masses of the country, and still more the occurrence of bits of sulphuret similarly imbedded, would afford good reason for believing a workable vein of copper ore to be in the neighborhood.

In all examinations of this kind, the action of water must be borne in mind. As streams sweep from hills

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into valleys, they carry with them fragments of various kinds of rock. By carefully observing these, and tracing them to their sources, the veins from which the metalliferous pebbles were originally detached may be found. Water also acts directly in exposing to our view the mineral wealth of a region, by making, in the different ravines and gulleys, so many natural geological sections in which we can trace the veins. These, even though barren, provided they contain the same gangue as the productive lodes of the district, deserve attention, as they may become metalliferous in the course of their descent into the earth.

It may happen, when the veinstone is much harder than the surrounding rock, that the joint action of air and water may wear away the latter more rapidly than the former, so that the vein may remain a kind of wall, protruding above the common level of the soil. Such a dyke exists at Mouzias, in Algeria, where several lodes of heavy spar and spathose iron, containing a little gray copper, traverse a soft and marly soil that offers little resistance to the action of water. In consequence, the heavy rains have washed away the softer clay, and left the more solid outcrop of the lodes standing. In some places this wall is fifteen or twenty feet high, and cuts all the different formations of the country.

The most careful examination of the surface, however, often fails to communicate any satisfactory information as to the metallic wealth of the region examined. Then artificial excavations become necessary. If the vein be well developed near the surface, an open cut or trench will often disclose its character. The more common me-

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thod of procedure, however, among the Cornish miners is what they term *shoding* or *costeaning*. This consists in sinking a series of pits about three feet wide, six long, and deep enough to penetrate the alluvial soil and sink a few feet in the rock. If the direction of the veins of the neighborhood is known, this line of pits should cross it at right angles. If the region is wholly unexplored, two series of pits must be sunk at right angles to one another. These isolated shafts are now joined by galleries, so that it is impossible that any vein should escape detection.

The presence of a promising vein being determined, the next thing is to make the necessary openings for working. Open cuts are out of the question, for the riches of a vein always lie deep below the surface, and the upper portions are usually quite poor. There are a number of points to be taken into consideration in excavations for mining purposes. The surface water and rain must be kept out of them, and the greatest care must be taken to get rid of the deeper water in the simplest and cheapest manner. It is necessary also to provide for the ventilation of the mine.

The first step, if the conformation of the country admits of it, is to devise an *adit-level* or horizontal gallery from the lowest possible point of an adjacent valley directly upon the vein. This will, of course, drain all the work above the level at which it intersects the vein, and the skill of the operator is shown in reaching this at the least expenditure of time and labor, and cutting it at the lowest possible point. Sometimes but a few feet, at others many fathoms of perpendicular descent can be

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drained by these galleries. The economy is great, as they save the constant outlay in machinery for pumping up the water. Of such importance are these galleries esteemed, that sometimes a number of mines are drained by a single adit driven at their joint expense. So long as the excavations are kept above the adit-level, it is of course unnecessary to use machinery for pumping, and when they have been sunk below it, the water need only be raised to it, and not to the surface of the ground. In large mines, every foot saved in this way is important, and large expenditures are justifiable, which will effect a slight reduction.

It is desirable, if possible, that the adit should be driven on the vein itself or close beside it, so that it may be broken into from time to time, and its character and richness determined. Where this is impossible, it must be driven to the vein. It is necessary that the adit should be inclined only sufficiently to allow for the ready flow of the water. If it be too near a dead level, it will fail to accomplish its purpose, if too steep, it will strike the vein unnecessarily high.

The next thing to be done is to sink a shaft, to intersect both the vein and adit or a cross-cut leading from the latter. If the vein be nearly vertical, it is customary to sink the shaft directly upon it, unless its *underlay*, or the angle it makes with the perpendicular, is too irregular, in which case it is sunk by the side of the vein and connected with it by cross-cuts. When the lode has an underlay of 45°, it is usual to sink vertical shafts upon it. The dip of the vein having been ascertained, it is easy to decide upon a point at which a

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shaft must be opened, in order to strike it at a given depth. After striking the vein, the shaft may be pushed through it, for some distance into the non-metalliferous rock. The vein can then be attacked, if necessary, both on its upper and its under side, by driving cross-cuts from the shaft. In the Lake Superior region, the shafts in veins of such an underlay are driven in the vein itself, following its dip, and the method has proved to be economical. In such shafts, a double tram-road is laid, and the ore is loaded on cars in the levels and run up to the surface. The verticle shafts are employed in England, and are always to be preferred when there are several parallel veins to be worked by the same excavations, or when they are used in part for the purpose of exploration. The size of the opening of a shaft necessarily varies with the purposes it is required to subserve. If it is to be used as an engine-shaft, or that in which the pumping machinery is placed, at the same time that ore is raised through it, it must be from twelve to fifteen long by six or eight wide.

Of course, the bottom of the shaft would soon become obstructed by the fragments of the workings, as well as flooded by water, if measures were not taken to remove both these accumulations. Buckets are provided for the ore, which are termed by the Cornish miners *kibbles*. In Cornwall, they are made of sheet-iron, and each holds about three hundred weight of ore. One hundred and twenty kibbles are supposed to clear a cubic fathom of rock. Until the shaft has got below the depth of a hundred feet, the only lifting arrangement necessary is a windlass, worked by hand. The kibbles and their ropes

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are so arranged that they pass one another in the shaft, so that when one bucket is descending, the other is ascending. As the shaft becomes deeper, greater force is required, and horse, steam or water-power is resorted to.

The machine employed for this purpose, is called a *whim*, and is simply the original windlass enlarged and set on end. It consists of an upright post turning in a socket at its lower, and in a beam at its upper extremity; a cage or drum, round which the rope is wound; and a pair of long arms, which correspond to the handle of the windlass. The beam in which the upper end of the axle turns, is supported by strong timbers firmly planted in the ground and strengthened by braces. In order to convert the horizontal motion of the rope around the drum, into a vertical motion in the pit, the ropes are passed over pulleys set in a frame work erected over the mouth of the shaft. The power is of course applied to the extremities of the arms. Steam is only used for shafts over two hundred feet in depth, after the value of the mine has become fully established. In this country, small horizontal high-pressure engines are usually employed; in Cornwall the low-pressure engine is preferred.

As the upper part of the shaft is exposed to all the changes of temperature of the surface, the rock will be liable to crumble and fall in. In order to avoid this, it is necessary to protect the walls of the opening with some sort of covering. For this purpose, timber is generally used, though sometimes its place is supplied by masonry. It is stripped of its bark, as that, by absorbing and retaining moisture, accelerates the decomposi-

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tion of the wood. With this exception it is as little dressed as possible. Resinous woods, such as pine, are much less durable than the harder varieties.

A second shaft is now to be sunk at a suitable distance from the first, and the two are to be connected by a gallery, usually termed a *drift* or *level*. The distance of these shafts varies with the nature of the surface, the richness of the vein, and the depth of it which can be worked. A hundred yards has been stated to be the average distance between two shafts in a vein of moderate width and richness.

The shafts being steadily prolonged downward, the mass of the vein is cut up into a series of parallelopipedons, by levels driven through it and following its direction. If the shafts are at too great distance apart for the convenience of working, the levels are connected by shallow shafts, called *winzes*. The usual perpendicular distance between the levels is ten fathoms or sixty feet, reckoning from the floor of the upper to the roof of the lower level. The customary dimensions of these galleries are six feet in height by three in breadth. By these the mine is fully opened, and if they are driven upon the vein, ore is continually being taken out, so that if the lode is tolerably rich, the expenses of the opening are more than defrayed. Sometimes it is convenient to drive the levels by the side of the vein, in which case, the wall is broken through from time to time.

The masses thus marked out are removed by *stoping* or working in steps, the object of which is to remove all the rock of the vein that is worth taking down. There

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are two methods of doing this, known as *underhand* and *overhand stoping*.

If it be determined to proceed by the first plan, a scaffold is erected in the shaft, six feet below the floor of the upper level, and the workman begins to take out the mass between that floor and the scaffold. As he advances, he fixes in the walls of the cavity, strong timbers, called *stulls*, upon which he lays a floor of plank for the reception of his debris. It is necessary that these should be very strong, as they have to support a great superincumbent weight of fragments of rock. As soon as the first workman has cut away a block six feet high, three wide, and six or eight long, another is set to work on a scaffold six feet below him, and when he has penetrated a like distance, a third attacks the rock six feet lower yet, and so on till the roof of the lower level is reached. In this way the working resembles a series of gigantic steps, each workman being six or eight feet in advance of the one next below him.

If the second plan, or *overhand stoping*, be resolved on, a scaffold is erected in the shaft, on a line with the roof of the lower level. A workman placed upon this, commences to cut away the rock at the re-entering angle made by the wall of the shaft and the roof of the level. He constructs a floor in the same manner as in *underhand stoping*. When he has advanced six or eight feet and removed all the ore six feet above the floor he has constructed, another is set to work six feet above him, and so on until the floor of the upper level is reached. It will be perceived that this method is the very reverse of the last, so that the men appear to be working un-

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derneath a great staircase, instead of on the face of its steps.

Each mode has its advantages. The former enables the workman to stand upon the body of the vein itself, with his work before him, and not liable to be injured by splinters from the roof; but he is also compelled to employ an enormous amount of timber to sustain the rubbish. The latter plan, with the exception of the occasional discomfort of his attitude is the easiest for the miner, as the separation of the ore is aided by the force of gravity. The amount of timber employed in this method is less than in the former, but the sorting of the ore is more difficult, because the rich ore is apt to be covered with the heap of rubbish among which it falls.

It is not necessary to enter into a description of the miner's implements, the picks, sledges, &c., or to take up space in describing the operation of blasting, as all this must be familiar to our readers. We may say, however, that water need not deter the novice in mining operations from using gunpowder. All he has to do, if he cannot dry the cavity, is to secure his powder in a tin case, or in a cartridge bag rendered impervious to water.

It sometimes happens that the rock is so extremely hard, that the ordinary tools produce little or no impression on it. This is the case in the Rammelsberg, where the vein is large and rich, but exceedingly difficult to work. To give an idea of its hardness, Dr. Ure relates an experiment tried there in 1808. A man set to work to bore a hole for blasting. He labored assiduously during 11 posts, of 8 hours each, in all 88 hours,

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without being able to get deeper than four inches. In accomplishing this, he wore out 126 bores, dulled 26 others, which had been retipped with steel, and 201 which had been sharpened, besides consuming 6¼ pounds of oil to give him light, and half a pound of gunpowder for the blast.

In cases of this kind, fire is employed to destroy the cohesion of the masses to be wrought. At the Rammelsberg, this agent is usually brought to bear upon the roof of the vault. Piles of faggots are so arranged throughout the galleries, that the top of each shall not be more than two yards from the roof of the vault. This having been attended to, together with the other work of the mine, during the week, the fire is kindled on Saturday. At 4 o'clock, in the morning, the fires are lighted, the fireman beginning in the upper ranges so that the vapors from below cannot stifle the newly made fire. He descends from level to level, kindling the pile throughout the mine, and does not get through his work till 3 o'clock in the afternoon. Sulphur and arsenic are burned off, loud detonations occur in the vaults, and some splinters of ore fall, though most of the heated mineral retains its place on the roof. The fire is left to itself till Monday morning, when a man again descends and extinguishes such of the fires as have not gone out. Should the action of the former piles be incomplete, new ones are built in the same spots, after the miners have stopped work for the day. On Tuesday, all hands are at work, detaching the friable mineral from the roof with long iron forks, and preparing new piles to be kindled again on Saturday.

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All these workings which we have described, require a support of some kind. In some cases, the rock is so friable that it is impossible to advance at all without attending to this before the excavations are made. These supports are either of timber or of masonry. The former is more frequently adopted; in this country it is exclusively employed.

To timber with *complete frames*, is to construct a sort of gallery of logs within the excavation. A floor piece or *sole* is laid, on which rest upright posts, inclining a little towards each other, so as to make the ceiling narrower than the floor. A cap is now put on the *standards*, and they are morticed into it so that they cannot possibly approach nearer to each other. When the rock is very friable, *facing boards*, which are planks, or spars of cleft wood, are placed horizontally behind these beams, both on the roof and on the sides. The size of the timber and the distance between the stanchions depend entirely upon the pressure to be resisted. When the floor is sufficiently solid, the uprights rest directly upon the rock. Sometimes only one side requires timbering, the other being sufficiently firm. In that case, pillars are set up only on one side; on the other, the joists rest in holes cut in the rock. It may happen that the roof alone requires support. Then the timbers are simply laid across the top, being secured at both ends in sockets cut in the rock.

When masonry is employed, it is almost always arched. Sometimes when the floor also requires attention, it is built in the form of an ellipse, like an egg-drain.

The processes of blasting, the combustion of the can-

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dles and lamps, as well as the respiration of the workmen, must soon thoroughly contaminate the atmosphere of the narrow underground passages we have been describing. The emanations from the mine itself, resulting from the decay of wood, the decomposition of minerals, the occasional evolution of arsenical and mercurial vapors, all contribute to the same results. It is therefore absolutely necessary to secure such a current through the various openings as shall sweep out these poisonous vapors, and furnish the workmen a sufficient amount of pure air for respiration. Numerous contrivances have been resorted to for the accomplishment of this necessary object. Very often it is effected by merely arranging the openings of two shafts at different elevations externally. The column of air within the mine, being lighter in winter and heavier in summer than that without, the air naturally flows out of the higher elevation in the former season, and the lower in the latter. In long galleries two compartments are sometimes made, the one larger than the other. In the smaller, the air sooner comes to the temperature of the rock, and this difference between the two compartments is sufficient to establish a current. These currents are often obtained by raising a chimney sixty feet high over one of the shafts, which has the same effect as sinking shafts at different external levels. There are also more complex contrivances for pumping the foul air or forcing the pure air in, which our space will not permit us to describe.

The ore which is separated with the vein-stone in mines, is rarely sufficiently charged with metal to be

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merchantable without some preliminary dressing. The methods of concentrating the ore will now demand our attention.

As the ores are but sparingly diffused through the vein, being mixed with a great quantity of stone, it is the miner's duty to make a preliminary sorting of them before sending them up to the surface. He separates those which seem to contain no metallic matter, from those which have ore diffused through them. The former are allowed to remain in the mine, where they are used for filling up in part, the cavities made by the progress of the excavations.

When the ores selected by the miner reach the surface, they undergo a second *sorting* by hand. The various pieces are broken up by hammers into small fragments, and are usually divided into three varieties: 1st, The gangue or stony matter, which is thrown away; 2nd, The rich ore which may be sent directly to market; and 3rd, The fragments which, containing little ore, are to be sent to the stamps or rolls for further dressing.

The latter, in order to undergo the final separation of ore from dead rock, must first be reduced to the proper degree of fineness. For this purpose, they are subjected to the action of machinery. One of the most common forms is a crusher, an apparatus composed essentially of two iron rollers revolving in opposite directions, worked by either steam or water-power. Their bearings are so arranged as to slide in grooves, and consequently, to allow the cylinders to be brought closer together, or to be separated to a greater distance. To prevent accidents from the sudden jar given to the ma-

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chinery by the harder pieces of stone, a lever is attached to a sliding bar and shoulder, so that its outer extremity when loaded by a suitable weight, will keep the rollers in sufficiently close apposition. When a fragment, so hard as to endanger the apparatus, becomes entangled between the rollers, the weight rises, the jaws open and allow the piece to drop. The ore to be crushed is gradually let fall between the two rollers from a hopper, and, as it passes through, is received into a cylindrical sieve, inclined towards the horizon. This, being agitated by the same power which moves the rollers, allows a portion to pass through upon the floor, while the rest, being too large for its meshes, falls into the buckets of an endless chain which carry it up to the level of the hopper, when it is again passed through.

In some cases a stamping-mill is preferred to a crusher. In this apparatus, a long horizontal axle is set in motion by steam or water-power. This axle is provided with a series of cams arranged in spirals round its circumference. Vertical wooden beams shod with heavy pieces of iron, are provided with tongues so as to be caught and lifted by the cams during the revolution of the axle. The tongues and cams are so arranged as to enable each iron shoe to give three blows during one revolution of the axle, in a constant succession, so that when one beam is falling, the beam next it is rising. The iron shoes fall upon the mineral contained in a large trough. This trough is provided with several openings, which have over them a grating of perforated sheet-iron. A small stream of water passes through the arrangement, sweeping out, through the holes of the

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grating, those fragments of ore which are sufficiently pulverized. They are received in a pit prepared for that purpose.

The size of the stamp-heads varies with the nature of the mineral to be broken. Their average weight in England, is from three to four hundred pounds. The heads are attached to the lifters by a wrought iron shank, which is let into the end of the lifter, and made fast by shrinking over it two bands of iron.

The ores thus comminuted are usually concentrated by washing. The principles upon which this process depends are very simple. If, for example, a number of substances varying in form, size and density, be swept along by a current of water, or allowed merely to fall through water, they will arrange themselves in accordance with the resistance or the impulse they experience from the fluid. If they are alike in form and size, but vary in density, they will after falling through water, arrange themselves in the order of their specific gravities, the heaviest being at the bottom, the lightest on top of the series of strata. If their form and density be the same, but their size different, the largest particles, moving more rapidly than the others, will of course arrive first at the bottom, and must necessarily occupy the lowest layer of the sediment. The reason for this is to be found in the fact, that though their volume increases as the product of their three dimensions, the surface exposed to the resistance of the water increases only as the product of two of these dimensions, so that the resistance is less in proportion in the larger pieces. If the pieces have the same volume and density, but differ

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as to surface, (which of course involves a difference of form,) it will be found that those which possess the greatest surface, being most resisted, fall slowest and form the upper layer.

From these considerations, it is evident that the ores to be dressed, should be, as nearly as possible, of the same size, as then they will subside in the order of their specific gravities, which is what the miner desires. Practically, this is effected by the use of sieves, which classify the pounded materials as to size. Their form is of course, beyond the control of art, and this interferes to a slight extent with the result.

It is evident that there are but three classes to which the broken fragments can belong. They must either be composed of the ore exclusively, of the non-metallic minerals exclusively, or of a mixture of the two. In the process of washing, the pure ore sinks to the bottom, the mixed ore comes next above it, while the top layer is composed of the non-metallic substances.

One of the most ancient methods of employing water for the purpose of classifying ores, was the use of the hand sieve. This is a cylinder closed at the bottom by a perforated sheet of copper. The miner fills it with the mineral he wishes to operate upon, introduces it into a large tub of water, and works it with a sort of undulatory motion. The water streaming up through the holes in the bottom, offers a variable resistance to the different substances in the sieve; so that the heavier or richer particles sink to the bottom, and the more earthly matters accumulate on the surface. These the miner scrapes off with a piece of thin iron, or with

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his hand, and repeats the operation, as long as the surface pieces continue poor. These are not all rejected; those which are considered metalliferous enough to pay for a second sorting being laid aside for further treatment. That which accumulates at the bottom is taken out and sent to market. This process is called jigging or sieve washing.

On the Continent of Europe, a modification of this method has been generally adopted. To a beam, one end of which carries a box which is filled with stones to act as a counterpoise, is attached by means of a rod, a sieve resembling that used in washing by hand. This rod is fastened to the beam midway between the turning pivot and the end, which carries another rod swung on a pivot. This is worked up and down in a cylinder, and communicates a plunging motion to the sieve. The process is precisely the same as in hand washing. For the sake of convenience a table is placed near the deep tub to receive the ores.

In Cornwall, copper ores are washed by a much better and larger apparatus. "This consists of a large box, covered with a tight wooden floor, in the centre of which, is a circular metallic trough, perforated with six holes, each about two feet in diameter, and into all these openings a sieve is closely fitted. A large piston working in a cylinder placed in the centre of this arrangement, and which is moved by an eccentric, driven either by water or steam power, is made to alternately raise and depress the level of the water in the box and consequently also in the sieves, which are fixed water-tight into the rings on the top of it. By this motion of the water, the

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particles of minerals contained in the sieves are made to arrange themselves according to their several densities, and when it becomes necessary to remove a sieve from its place for the purpose of scraping off the less valuable and lighter portion of its contents; its place is supplied by another, which is kept ready filled to occupy the same ring when required."

"Of the portions which are scraped off from the surface of the sieve, the lightest contains little or no metalic ore and is thrown away; but the second, consisting of a mixture of gangue and metalliferous substances, together with the finely divided dust which passes through the holes of the sieve, is sent to the stamping mill, where it is reduced to the state of much finer powder, by which treatment greater facilities are afforded for its separation from earthy impurities. When the ores are not stamped dry, the water and *work* (fine sand) escaping through the gratings of the machine are conducted into a sort of reservoir, where the heavier particles are first deposited, and the poor and consequently lighter parts, are removed to a greater distance. By this process, a certain classification of the work is effected, as those portions which have been carried by the force of the water beyond a given point, are collected in a separate basin from those which have not arrived so far from the stamping-mill." *

The arrangements for washing the finely pulverized ores, varies in different places, and with different ores.

The *German chest* is a long box placed in a slightly inclined position, and having in its lower end, a series

* Phillips' Metallurgy, p. 113.

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of holes, closed with wooden pegs. At the higher end, a platform is placed to contain the ores, over which plays a small stream of water. This carries off in suspension the finer particles of the ore and, deposits them at distances varying inversely as their specific gravity. As soon as the box is full of water, the stream is stopped, and the lower peg being withdrawn, the water and fine powder are allowed to flow off into reservoirs, where the solid matter subsides. As the chest becomes gradually filled with the deposited sand, peg after peg is withdrawn, till at last, when quite full, the uppermost peg is taken out. The heaviest ore is found to be deposited near the head of the pit, and the others distributed in the order of their richness, at varying distances. The first is ready for smelting, the other portions require further treatment.

The *sleeping* or *twin tables* are two inclined planes, about twenty-five feet long, placed side by side, and provided with ledges to prevent the ore from running off at the sides. At their upper extremities, is an apparatus, worked by a small water-wheel, for thoroughly incorporating the fine ore with water. Thus mingled, it is introduced on the upper part of the planes, and a stream of water allowed to flow over it. This separates the different substances in the order of their densities, the lighter being swept off by the current. The workman accelerates this process of separation, by sweeping the ore up the planes with a small broom, until he is satisfied that the ore is fully concentrated, when it is suffered to fall through an opening near the lower end of the plane, into receptacles prepared for it. The inclination given

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to these tables varies with the fineness of the powder they are expected to sort, being greater the coarser the grains.

The *percussion table* is also an inclined plane, but it is swung by chains, which at the upper extremity, attach it to fixed beams, at the lower to a moveable lever, cams on the axle of a water-wheel, strike on an upright connected with the table, and subject it to repeated concussions. The ore is mixed with water and allowed to flow over the surface, as in the last described apparatus, but the repeated jars, assist in the separation of the light from the heavier particles, so that the apparatus is, in principle, a sort of combination of the sleeping table and the jigging machine.

In Cornwall *buddles* and *racks* are used instead of the tables.

The *nicking-buddle* is a long inclined trough, or cistern, resembling a German chest. At its head is an inclined shelf, higher than the floor of the cistern, terminated above by a wooden head-board, provided with an opening closed by a plug, which regulates the admission of water from a little dam behind it. The ore having been placed on the higher shelf, a stream of water is let on, meanwhile a boy stationed in the pit, alternately smooths and notches the layer of ore, with a sharp shovel. The ore is soon washed from the head, and when it has fallen in the body of the apparatus, the boy continually sweeps it back towards the head again. This facilitates the separation of the light from the heavy particles, the former being carried down towards the bottom of the buddle. When the deposit of heavy par-

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ticles has sufficiently filled the cistern, the light gangue, suspended in the water, is drawn off. The heavy sand is drained, and divided into three portions according to its richness. The ore nearest the head of the buddle is usually rich enough to be smelted; that next to it is laid aside for a second puddling, while the lowest and lightest is sent to the rack.

The *rack* consists of a smooth wooden flooring, with strong ledges around it, inclined to the horizon, and provided, like the buddle with an upper shelf and headboard. It rests upon pivots, so as to enable the workman, when desirable to turn it on the pivots. The water is let on to the lower level over a flap, swung on leather hinges.

The ore is laid on the higher shelf, and alternately grooved and flattened by means of a wooden hoe. The water carries it down to the lower level, where it is moved by a rake to the highest point of the arrangement, the water flowing continually over it. A small broom is also used to complete the washing, the earthy matter being suffered to flow out into reservoirs prepared for its reception.

When a sufficient layer of mineral has by this manipulation been collected on the table, it is made to take a quarter revolution on its axis, and when in a vertical position, is caught by a wooden spring, which holds it firmly in that situation.

The person working the frame, now washes off the ore by the use of a wooden bowl with a long handle, which causes it to fall first into the angle, formed by the meeting of one of the sides with the floor, and alternately

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into boxes placed beneath for its reception. In this, as in the preceding examples, the richer ore will be found to accumulate at the upper end of the inclined plane, and therefore the washed ore is divided into two parts, each of which falls into a different receptacle.

"This division is made by a fillet, placed on the side of the rack at about equal distances from its two extremities, and which, when the plane is brought in a proper position for washing off the deposited metalliferous grains, forms a dam, and causes that which is deposited in the upper part of the floor to fall into one box, or *cover*, whilst that which is deposited in the lower, falls into another."*

* Op. cit.

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CHAPTER IV.

MINES OF COPPER.

COPPER is very widely distributed over the surface of the globe, and occurs in many geological formations. Often it exists in mere detached minerals, not connected with any great mass of ore, and at others it is so abundant that it may be considered inexhaustible. The great mining districts have so far been found in two distinct geological positions; first, in the older crystalline rocks, especially the metamorphic palæozoic, and in the igneous formations associated with them; secondly, in the strata lying between the coal measures and the lias, which is the lowest member of the Jurassic or oolitic group. The best examples of the former mode of occurrence are the mines of Cornwall, Australia and Lake Superior. The veins are either segregated, or true fissure veins, the former being sometimes large and productive, but the latter being more permanent. Of the second mode of occurrence, the schists of Mansfeld, and the Ural mines are examples. In the new red sandstone of our country, which is usually referred to the Triassic group, but lately classified among the lower Oolitic rocks, copper ores are also found. Above the new red sandstone few important deposits of copper have been discovered.

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EUROPEAN MINES.

British Mines.—Cornwall is the great district of British mining, and as the mines of that region are usually selected as a basis of comparison with other deposits, it will be well to consider somewhat carefully its geology.

The mines of Cornwall occur either in granite or the schistose rocks that accompany it. Of these, the *killas** or greenish argillaceous slate and the *growan* or granite are the most important for the copper miner. Porphyry, called by the miners, *elvan*, also occurs, but it is chiefly valuable for the tin which it carries. The term *elvan* is likewise applied generally to any rocky mass that occurs in the slates and granites and displaces the rocks. The porphyry usually occurs in long narrow dykes, some of the seams having been traced for twelve miles.

The granite is found in six great isolated masses, as well as in smaller patches. The great masses have a general linear direction northeast and southwest. It is remarkable for carrying a great deal of schorl or black tourmaline, which is especially abundant along the confines of the granite and slate. The latter rocks abut abruptly upon one another, the only change which is noticeable in the killas being a condensation of the mass, the granite frequently penetrating it. De la Beche makes a distinction between the mica and hornblende slates, and the grauwacke group, a collection of sedimentary deposits varying from the finest roofing slates to the coarsest possible conglomerates.

The same eminent geologist divides the mining district of Cornwall and Devon into six groups:—1st. Tavis-

* This term is also applied to slate in general.

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tock, bearing copper, tin, and silver lead; 2d. St. Austell, containing tin; 3d. St. Agnes; 4th. Gwennap, Redruth and Carnborne, a copper region; 5th. Breagin, Mazarien and Gwinear, producing tin, copper, lead and silver; 6th. St. Just and St. Ives, bearing tin chiefly. The ores of copper and tin are always found in the neighborhood of the granite or porphyry.

The system of the veins of this district is exceedingly complex. Mr. Carne's classification, adopted by Dr. Ure, in his Dictionary of Arts, Manufactures and Mines, is as follows;

1. Veins of elvan; elvan courses, or elvan channels.
2. Tin veins or lodes.
3. Copper veins running east and west; east and west copper lodes.
4. Second system of copper veins, or *contra* copper lodes.
5. Modern copper veins; more recent copper lodes.
7. Clay veins, of which there are two sets, the more ancient called *cross-fluckans*, the more modern called *slides*.

These divisions appear to be the result of an analysis altogether too refined. Sir H. de la Beche, who paid great attention to these mines, does not attempt to assign definite ages to the copper veins, so that the third, fourth and fifth divisions in the above table may be united in one. As to the tin veins, they are generally believed to be older than the copper lodes, but even this idea may be dismissed, since it has been ascertained that the very same lode may carry tin in one part of its course and copper in another. The second division of

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the table may therefore be incorporated with the three following it. We shall then have three classes of veins.

First, the *elvan courses*, which follow nearly the range of the granite rocks, traversing them, and are themselves cut by the true productive lodes.

Second, the *great metalliferous lodes*, which have the same general direction with the elvans, but which intersect them and consequently are more recent.

Third, the *cross-courses*, or veins and fissures which run north and south, cutting the east and west lodes at angles varying from seventy to ninety degrees. They carry argentiferous lead in some places, but are generally barren, being filled with clay. Their date is modern, being supposed to have occurred later than the cretaceous period. They are themselves occasionally cut by what are called the east and west slides.

Of these systems of veins, we have only to notice the copper lodes. Near the surface, where they have been exposed to atmospheric influences, they are much decomposed, and abound in *gossan*. This is a mixture of quartz with more or less oxide of iron, containing also insoluble combinations of other metals. The theory of its formation is simple. The vein-stone with its metallic contents, having been subjected to the influence of oxygen, has had soluble sulphates formed in it, which have been subsequently leached out by rain water. Sulphate of iron, decomposing readily, leaves behind it the hydrated oxide of that metal which gives its foxy red color to the mass. The less alterable minerals, gold, ores of silver and tin, remain behind. In the English

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gossans, silver occasionally occurs in sufficient quantity to be worked. Gold is found in many of them, to the extent of one or two ounces to the ton, and tin has been so abundant that the gossans have been mined for that metal. The depth of this decomposition varies from twenty to thirty fathoms. All gossans are not equally valuable indications of the presence of valuable mineral at greater depth, and experience enables the miner to form an idea of the prospects of a mining estate, by a careful inspection of this overlying rock.

The lodes, below the point at which the atmosphere ceases to act, contain chiefly copper pyrites, mixed with other ores of copper and with sulphuret of zinc. The ores are not uniformly diffused through the veins, but occur in masses of variable size, connected by threads and strings too small to be worked with advantage, yet distinct enough to be followed by the miners. The width of the veins averages six feet, though enlargements to the extent of twelve feet occasionally occur. The gangue is usually quartz, often mixed with green matter resembling chlorite. The veins are generally accompanied by argillaceous bands called the *fluckan of the lode.*

The productiveness of the lodes vary with the nature of the "country," and with the displacements to which they have been subjected. If they ramify as they descend, the ore diminishes; but if the various strings coalesce downwards, the product of ore increases. In like manner, when different veins unite, the quantity of ore usually increases. In the Gwennap district, the east and west veins all become productive, where the

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great counter-lode cuts them. As a general rule, the smaller the angle at which two lodes cross one another, the better are the prospects for a great amount of ore. The elvan dykes have also been found to exert a very beneficial influence upon the richness of the mine. The nature of the rock which the veins traverse also affects the lode. The most productive portions are always in the neighborhood of the point where the granite meets the killas. No general rule can be given for determining the productiveness of a lode in either of these rocks, there being great variation, in this respect, in different mines. Thus, of two parallel tin lodes, only a mile apart, one was unproductive in the slate, and rich in the granite, while the other was just the reverse. The slates were formerly considered the best "country" for copper, but rich mines have been worked in the granite not very far from its junction with the killas. The characters of the rock in any formation seem to influence the yield of copper. Thus, in the Gwennap district, the red killas is considered unproductive and the bluish gray variety alone is believed to justify extensive working.

As to the yield of a mine at various depths, it has been generally believed that a true vein grows continually richer as it descends. Some doubt has been recently cast upon this opinion, from the fact that in certain old mines this gradual increase in value stopped at a very moderate depth, beyond which the metallic contents of the vein remain stationary, or, according to some authorities, actually diminish. It has been asserted that the results of working prove that a vein, which is poor at

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the surface, increases in richness to a certain depth, where it reaches its maximum and then diminishes in productiveness, while a lode, rich at the surface, continues good for a certain distance and then begins to decrease, at much less depth than the poorer lode. These statements have been denied on the ground that some of the deepest mines in Cornwall continue to furnish great abundance of ore. In connection with this question, it must not be forgotten that the time of greatest prosperity of each mine has been when its workings had reached a moderate depth, a fact which seems to show that the increase of ore in the lode at the greater depths, if it really occur, is not sufficient to meet the augmented expense of raising it from such very deep levels. For example, in 1815 the Dolcoath mine was the richest; in 1817 the United mines stood first; in 1822 the Consolidated mines gave the largest product, and since 1845 the Devon Consols have held the first place. The deepest mines have been sunk over 2000 feet.

It is very important to consider the dip; a vein which has an inclination varying much from the perpendicular, being rarely very valuable. In a lode which often changes its inclination, those portions which are most nearly perpendicular, are usually the richest.

These mines are worked on a grand scale, and with great skill. The Great adit reaches nearly five and a half miles, in a direct line; and if all its ramifications be taken into account, its length is thirty-five miles. At its deepest point, it is seventy fathoms below the surface. We subjoin a very brief sketch of some of the principal Cornish mines.

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The *Dolcoath Mine* is the oldest in Cornwall, having been worked with little interruption for a century. It is three hundred fathoms deep. It has paid out £300,000 in dividends. In the thirty-six years from 1814 to 1848, it furnished 238,059 tons of ore, worth £1,361,681.

The Great Consolidated Mines are very celebrated. In 1848, the workings were sixty-three miles long, and had made a profit of £700,000. From 1819 to 1840, these mines cleared £500,000, besides expending £100,000 in opening the United Mines. During the last twelve months of that period, they yielded 17,283 tons of ore, worth £100,279. From 1840 to 1848, there were taken out 83,660 tons, sold at £490,543, of which, owing to the heavy expense of the workings, only £32,000 was divided among the stockholders. In March, 1854, no dividend having been declared for more than three years, the price of shares went down ninety per cent. below par.

The *Devon Great Consolidated Company*, usually called *Devon Consols*, has made enormous profits. They began in August, 1844, with 1024 shares, at £1 per share, paid in. The ground was leased of the Duke of Bedford for twenty-one years, at a royalty of one-fifteenth, to be raised to one-twelfth after £20,000 had been cleared. The lode, at eighty-four feet from the surface, was eighteen feet wide, "carrying an immense gossan." At the depth of one hundred and five feet, the great deposit was reached. In the first three months of regular working, the mine cleared over £15,000; the next year, 1846, the profits were £39,590. By 1850, ten shafts had been sunk in the lode, the deepest having

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reached six hundred feet, and one thousand persons were employed about the mine. Up to January, 1853, £358 had been paid in dividends on each share, and the original shares of £1 sold for £430. Up to that time, 131,141 tons of ore had been taken out and sold for £882,742. In 1854, the mine produced 23,174 tons. At present, the mine pays dividends every two months, and the stock sells at £410 per share.

During the year 1853, sixty English mines paid out in dividends £329,015, of which two, the Devon Consols and the Wheal Buller, paid £110,464. At that time, shares in the latter mine on which £5 had been paid in, were worth £1,025.

The average annual production of this mining region has steadily increased until the past year, when it fell somewhat short. In the Appendix will be found a table expressing it. It will there be seen that the product for the year 1853 was more than three times greater than the annual product at the beginning of this century, but that the percentage was one-third lower. The average yield from 1771 to 1786 was twelve per cent. of copper, that of the first twelve years of this century, 8.95; of the next twelve, 8.4; of the next twelve, 8, and of the next, 7.7. In 1853, the product was only 6.6, so that although more ore was sold than ever before, and at a higher rate, many years exceeded it in the actual amount of pure metal obtained from the ore. The average of the first three quarters of 1856, was 6.27, the total produce being 143,200 tons.

The number of copper mines now worked in England is one hundred and seven, seven of which are not selling

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ores. Of those which are selling, twenty-six are paying dividends. The entire amount of capital originally invested in all the mines is £1,078,092, on which £2,294,478 have been paid in dividends. The annual dividend is £291,282, or one hundred and thirty-four per cent. on the capital invested in dividend-paying mines. In 1854, the number of mines was somewhat larger. Robert Hunt says that one hundred and eleven mines sold in that year ores in quantities above fifty tons each.

France. There is no copper mine of any importance in this country. Some time since, mines at Chessy and Saint Bel were wrought, but they are now abandoned. The chief interest attaching to them is to be found in the magnificent crystals of azurite they produced.

Prussia. Mansfeld has long been celebrated as an exception to the ordinary laws of copper-mining. For centuries a deposit having none of the characteristics of a regular vein, has been worked to advantage. The cupriferous rock is a regular member of a geological series, and though not more than two or three feet thick, and containing a very small percentage of copper, its great extent and extreme regularity admit of its being profitably worked. The ore is gray copper containing silver, and the rock which bears it is a bituminous marly slate.

Near Stadburg, in the district of Liegen, is a silicious slate which contains numerous particles of carbonate of copper. These are dissolved out by sulphuric acid, and precipitated by metallic iron.

Regular veins of copper also occur in various parts of the kingdom. The entire yield of the country amounted, in 1850, to 1450 tons.

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Austrian Empire. By far the largest portion of the copper produced by this empire comes from its dependency Hungary. In Lower Hungary, at Schemnitz, the mines were formerly valuable, but the region is now more celebrated for its mining school than for its productiveness. At Schmöllnitz, the copper ores are argentiferous, as they also are in the Banat.

At Tsiklova, in the Banat, there is an establishment for smelting the ore and separating the silver from the copper. The process will be described in the next chapter. The ores of the Banat occur in irregular deposits, near the junction of the sienite with metamorphic Jurassic rocks. They consist of copper pyrites, with gray copper carrying silver, blende, iron pyrites and a little gold. They do not yield more than four per cent. of copper after sorting by hand.

The annual product of the empire is a little over 3,300 tons.

Spain. The mines of Rio Tinto are the oldest in the country, having been worked by the Romans. The water issuing from the old workings is now treated with iron, furnishing copper by cementation. In 1833, one hundred and forty tons were obtained in this way. English companies are now working the Linares mines, which yield both lead and copper. The entire produce of the kingdom for 1849 is estimated at 450 tons.

Italy. The Tuscan mines are the best known in Italy, and they do not produce much. The ores of Monte Catini occur in contact deposits, and, contrary to the usual rule, grow richer as they descend.

Turkey. This country produces much good copper

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Russian Empire. The most extensive mines are in the neighborhood of the Ural Mountains. On their western flanks, in the governments of Perme and Orenburg, the beds of the Permian system are cupriferous and resemble the copper schists of Mansfeld. The ores, chiefly malachite, are distributed through thick, gray, flag-like grits. These contain only about $2\frac{1}{2}$ per cent. of ore, but the beds are so large that, even this small quantity pays well for extraction. The metal obtained from them is of very fine quality, and in great request for making bronze. They furnish about 260 tons annually, and pay the government a profit of about $40,000.

On the east side of Ural Mountains the most valuable deposits occur. The principle mines are the Gumeschewskoi, the Bogoslowski and those of Nijny Tagilsk.

At the former place there are no regular veins. The mine has been worked for more than a hundred years, on bunches and nests of copper ore, chiefly malachite and red oxide, contained in argillaceous shales. The malachite is in large masses; a cube, three feet and a-half in diameter, was taken from this mine.

The Tarjinsk mines near Bogoslowski, occur in a Silurian limestone, the strata of which alternate with beds or dykes of trap. Along the lines of contact occur deposits of clay, in which the copper ores are found in bunches and nests. Fine crystals of native copper occur here.

At Nijny Tagilsk, the ore lies in hollows of the eruptive works, and is mixed up with lumps of limestone and and other rocks. At the depth of 280 feet there was

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discovered a mass of malachite, estimated to weigh over 580 tons.

The average annual product of the Ural mines during the ten years preceding 1848, was 3720 tons of copper. In 1850 it exceeded 5400 tons.

There are other mines in the Caucasus, in the Altai and in Finland. Those of the Caucasus contain much ore and give evidences of having been extensively worked long since. The mines of Altai yield an annual product of 400 or 500 tons.

The average annual amount of copper produced by Russia, has been 4,540 tons. It is on the increase. In 1849 it was 6,546, and in 1850, 6,449 tons. But little is exported.

Norway and Sweden. There is not a very great amount of copper produced by this northern Peninsula. That obtained in Norway is reputed better than that from the Swedish mines.

The mines of Alten, in Norway, latitude 70°, are the most northern in the world. They have been worked by an English Company since 1826; the formation in which they occur belongs to the metamorphic palæozoic or azoic, with which are associated diorite and hornblende. At Kaafjord, the ores occur in igneous rocks cutting slates. In the former alone they are productive, often, indeed they disappear entirely in the slates. On the Raipasvara Mountains, a few miles from the last named locality, another group of copper lodes occurs in compact subcrystalline limestone, intercalated with slates. The principal vein is six feet wide, dips vertically, and contains near the surface, gossan with car-

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bonates and arseniates of copper but lower down the ore is variegated. The veins are unproductive in the slate. At Röraas, there are no veins, the ore being disseminated in chlorite slate, forming "fahlbands."

The deposits in Sweden occur chiefly in quartzose, micaceous and calcareous beds, contained usually in gneiss. Dalecarlia is the principal mining region. The mines of Garpenberg, in that province, have been worked since the twelfth century and are now 1000 feet deep. At Areskuttan, the ores are pyritous, and diffused through crystalline schists, forming fahlbands. At Gustavsberg, the fahlband averages thirteen to sixteen feet in thickness and often exceeds that. The ore yields only from three to four per cent. of copper.

Falun is a famous mining region, now nearly exhausted. The ore is poor, containing, after picking by hand, only $3\frac{1}{2}$ to 4 per cent. of copper. The rock in which it is contained, is a gray quartzose mass, containing little plates of mica. It is divided into irregular ovoid masses, by curved or undulated bands of chlorite, called "skölar." Along these are found the principal concentrations of the ore. The Storgrufva, or great mine, has been worked for centuries upon the larger of these masses, which is now found to be a huge inverted cone, with a rounded apex. The surface dimensions of the mass, are 800 by 500 feet. The interior is chiefly iron pyrites, the copper ore lying outside and forming a kind of envelope for it. The depth of the workings is about 1,100 feet.

The entire produce of Sweden in 1850 was a little over 1,400 tons, that of Norway, for five years before, averaged annually 567 tons.

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AFRICAN MINES.

Algiers. Near the foot of the Moazaia Pass, a copper mine has been worked for some time. The veins consist of spathic iron and grey copper ore, and are found in strata belonging partly to the gault and partly to the middle tertiary.

ASIATIC MINES.

India. Copper is found in the Ramghur Hills, about 150 miles from Calcutta. The ore is said to be abundant, but the mines are badly worked. The natives smelt the ore with charcoal.

Japan.—The copper from this secluded empire has long been celebrated for its purity. About a thousand tons are annually exported, chiefly to China and Holland. But little is known concerning the mode in which it occurs. From what Kæmpfer says, much of it would appear to be native. We quote his words.

"It is at present dug up chiefly in the provinces of Suruga, Atsingo and Kijnokuni. That of Kijnokuni is the finest, most malleable and fittest for work of any in the world. That of Atsingo is coarse, and seventy cattis of it must be mixed with thirty cattis of the Kijnese to make it malleable and fit for use. That of Suruga is not only fine and without faults, but charged with a considerable quantity of gold, which the Japanese at present separate and refine much better than they did formerly, which occasions great complaints among the refiners and Brahmins on the coasts of Coromandel. All the copper is brought to Saccai, one of the five imperial towns, where it is refined and cast into small cylinders,

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about a span and a half long and a finger thick, As many of these cylinders as amount to one pickel, or 125 pounds in weight, are packed up into square wooden boxes and sold to the Dutch. There is besides a sort of coarse copper, which is cast into large, flat, roundish lumps or cakes, and is bought a great deal cheaper than the other, as it is also much inferior in goodness and beauty."

AUSTRALIAN MINES.

Several mines have been worked in this great island, in a district not very far distant from Adelaide. The most celebrated of these is the Burra-Burra mine.

The vein occurs in a rock corresponding with the killas of Cornwall, and contains the green carbonate and the red oxide of copper. So productive is the mine, that, notwithstanding its distance from Adelaide, (eighty six miles,) the badness of the road, the want of wood for timbering the mine and smelting the ore, very large profits have been made. The mine was opened in September, 1845. Up to January, 1850, only £6 had been paid in on each share, yet the stock was quoted at £157. In March, 1853, a dividend of £5 per share on 2464 shares, was paid. The whole amount of dividends paid from the opening of the mine to that date was £135 per share. In August, 1851, the discovery of gold was made and the miners were all attracted to the deposits of the more valuable metal. The produce of the six months, ending on September 30th of that year, was 10,732 tons of ore, in which the profits were £49,506. The directors refused to declare more dividends till more

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workmen could be obtained. Since then the payment of dividends has been resumed. The last paid was on June 4th, 1856, amounting to £5 per share. Up to that time the whole sum paid in dividends was £170.

Kapunda mine is next to Burra-Burra in richness. It shipped to England in 1846 and 1847, 2768 tons of ore, yielding from 20 to 50 per cent. of copper.

The entire amount of metallic copper furnished by the Australian mines between the years 1844 and 1853 is stated by Whitney to have been 19,620 tons. The gold excitement having caused a great falling off in the produce of copper, the mines have not yet fully recovered.

SOUTH AMERICAN MINES.

Peru.—The copper ores of this country occur in two distinct formations, in the granitic and igneous, and in stratified rocks. In the former, whatever the nature of the ores, they never contain silver. The latter, besides regular silver ores and beds of argentiferous galena, also carry silver in the copper ores.

Near Antarangra a vein is worked which furnishes rich ores. These are smelted and yield a regulus, containing 50 per cent. of pure copper, which is sent to England to be worked. Near Colcabamba is another furnace, smelting ores which occur in a segregated mass in the granite. There are numerous veins of argentiferous copper ores in the districts of Niñobamba and Castra Virequa, which were formerly wrought very extensively by the Spaniards. Recently several companies have been formed in Peru to resume the workings. The amount of copper furnished by Peru is not exactly

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known. Mining, like every other pursuit, is much retarded by the political commotions of the country.

Chili.—Domeyko divides this country into two ranges of mountains, the Andes, and the Cordilleras of the coast, which are made up of three formations belonging to different geological epochs. The coast range consists of granitic or porphyritic masses running into diorite and greenstone. The rock found most frequently in the neighbourhood of metallic veins is a green porphyry in white felspar. This formation occupies the entire Pacific coast and extends as far in the interior as the eastern slope of the Cordilleras of the coast. Here begins a secondary stratified formation of an epoch anterior to the upheaval of the Andes. This rests upon the first named formation, which makes its appearance beyond them on many points of the loftiest ridge of which it often forms a portion of the highest peaks. The first named formation is barren, but this contains numerous metalliferous veins. It appears to belong to the Jurassic or cretaceous system. In the north, it contains calcareous and compact fossiliferous rocks, but to the south these entirely disappear. Throughout they are subordinate to the stratified porphyry and compact schistose or brecceoidal rocks that form the bulk of the chain of the Andes. This secondary formation varies in its distance from the coast and in its elevation. In the province of Atacama, it is twenty or twenty-five miles from the sea and has an elevation of 1500 feet; in the southern provinces it is not found within twice that distance, nor until a great altitude is attained, sometimes near the summits of the Andes. The tertiary beds, which

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have been deposited since the uplift, rest upon this secondary formation.

The gold veins are found in the old granite masses; the copper devoid of silver, antimony or arsenic, among the diorites, porphyries, sienites and other eruptive rocks in the vicinity of the secondary formation. The chlorides and native amalgams of silver are found near the line of contact of the primary and secondary formations; arseniates and sulpho-arseniates of copper and silver farther east, and argentiferous sulphurets of copper, sulphuret of lead, argentiferous blende and pyrites still nearer the Andes.

The district to the north of the valley of Huasco is very rich, especially in silver. In 1842, there were one hundred mines of silver, four of gold, and forty of copper in operation in the department of Copiapo alone. In 1850, the silver mines had increased to two hundred and ninety, the gold to six, while those of copper had diminished to thirty.

The mines in the vicinity of Copiapo were originally worked for gold, which was produced in great abundance by the upper part of the vein. When that metal began to fall off, copper took its place. In 1845, there were fifty mines at work, producing twenty-five per cent. ore, most of which was sent to England, though a portion was smelted on the spot. The principal vein at Cerro Blanco was worked for silver, the chloride of which was found in the upper part of the vein. At a depth of two hundred feet, both this and native silver had disappeared, and gray copper, rich in silver, took its place. Lower down it passed into gray copper and galena, and

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before the miners had reached the depth of six hundred feet, copper and iron pyrites constituted the entire contents of the vein. It was then abandoned by the original holder, and finally sold to an Englishman, who erected furnaces on the spot, smelted the ores which contained from twenty-five to thirty per cent. of copper, and sent the produce through Huasco.

South of the valley of Huasco, and nearest the coast, the most important mines are those of San Juan and Higuera. They occur in diorite, and furnish oxide of copper and copper pyrites. In 1845, their product exported was over 5,800 tons, besides what was smelted in Peru. Lieutenant Gillies reports their production in 1851 to be 4,500 tons. At Los Camerones, a vein enclosed between dioritic rocks composed of white feldspar and black amphibole, crops out on the southern face for nearly half a mile. The surface ores are carbonates, silicates and oxides; the deeper, copper pyrites and erubescite. The gangues of the oxides are argillaceous and ferruginous, containing micaceous iron; while those of the sulphurets are quartzose, containing much tremolite. This is an old mine, and at one time produced ores of fifty per cent. At present, it is worked by an English company, who take out 1200 tons a year, averaging from fifteen to twenty per cent. Those which yield more than twenty-four per cent. are shipped to England; those of seven and eight per cent. are rejected, and the rest are smelted on the spot in reverberatory furnaces, the fuel used in which consists of arborescent cacti and branches of shrubs. The department of Coquimbo is also abundantly supplied with copper ores.

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A large amount of this copper is smelted on the coast and sent off either as regulus or as pig copper, though some of it is worked up into sheathing and sold at Valparaiso.

Argentine Republic. Some valuable ores of copper have been discovered in the Maldonado mountains. They are native copper, red oxide of copper, and erubescite.

MINES OF THE WEST INDIA ISLANDS.

Jamaica. Several English companies are now engaged in working the mines of this island, some of which promise very well. The stratified rocks of this island belong to the Silurian age, but there are large areas of porphyry, granite, trap, greenstone, gneiss and chlorite slate.

The mines are not yet fully developed, and our information concerning them is scanty. The *Clarendon Consols*, in Clarendon Parish, has a large lode, frequently disturbed, composed of porphyry and siliceous matter with spots of yellow ore. It is hard, and as yet has been very little worked. The capital is £80,000. *Wheal Jamaica*, or Charing Cross Mine, in the same parish, is in the south-east flank of the same mountain which contains the last-named mine. The lode is four or five feet wide, underlying from ten to twelve inches in the fathom. The mountain, rising to a height of eight hundred feet above the valley, affords a good opportunity for cutting adits, which have been driven at distances of twelve or thirteen fathoms apart. The upper levels are ferruginous, but free from gossan at a moderate depth below the surface. The veinstone is

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quartyose, carrying, in the fifty-eight fathom level, yellow pyrites and a little gray ore, mixed with carbonates and silicates. The ore is found in branches, some of which are a foot in width. The surrounding rocks are porphryites. The nominal capital is £100,000; though there had been issued, up to the date of the last report which we have seen, but 35,000 shares of £1 each, on 25,000 of which 12s. had been paid in.

On the west side of the Liguanian mountains, a range of limestone hills two thousand or three thousand feet high, at Mt. Salust, there are seams of crystalline garnet rock carrying yellow copper. *Simpson's lode*, five feet wide, is composed of granite carrying yellow ore.

Cuba. Formerly the mines on this island were considered very valuable, and did actually produce large quantities of excellent ore. A few years ago, they fell off their yield, but seem to be at present rising again in importance. The ores are not believed to be in regular veins, but in beds and masses, subordinate to igneous rocks, especially greenstone and serpentine. The gangues are chiefly quartz, but sometimes limestone. The principal ore is the yellow sulphuret or copper pyrites, which is occasionally mixed with hydrated oxide of iron; while near the surface, are found carbonates, oxides and silicates. Some very remarkable ores have been sent in from this island. From the neighborhood of St. Jago we have received a black ore, in great masses, averaging about ten per cent., containing scarcely any gangue, but composed almost entirely of iron pyrites and covelline, or indigo-copper. A yellow copper sand, as light as flour, but containing thirty per cent. of copper, has also been sent in.

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There are two principal companies, both English, now at work on the island. The *Cope* mines, or the consolidated mines of the Cope association, are the most important. They have been successfully worked since 1834. Their product has fluctuated considerably since 1836, the highest annual yield being 22,741 tons, and the lowest 2,077. The average for ten years, ending in 1849, was nearly 19,000 tons. For the quarter ending September 30th, 1856, this company sold in Swansea, 3,529 tons of ore for £52,325 11s., while all the other sales of Cuba ore amounted to 467 tons at £26,092 11s.

The *Royal Santiago Mining Company* was formed in 1837, and has 17,000 shares, on each of which £13 was paid in. From 1840 to 1845, 55,540 tons of ore were raised, at a cost of £247,043, or about $22 per ton. They brought $557,533, thus yielding a clear profit of £48 per ton. Up to 1848, £33 4s. had been paid in dividends, but since then, the mine has been worked at a loss. In 1853, an assessment was levied on the shares.

COPPER MINES IN THE UNITED STATES.

In describing the valuable deposits of this mineral which occur in this country; the arrangement of Whitney will be adopted. He describes the American mines under three heads, I. the Lake Superior Region, II. Copper deposits of the Mississippi Valley, and III. Cupriferous deposits of the Atlantic States. The latter he divides into three groups.

1. "Copper-bearing veins of the Appalachian chain, in rocks of the metamorphic palæozoic age; ores chiefly

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pyritons; deposits mostly in the form of segregated veins; localities numerous extending along the flanks of the great Appalachian chain, from Vermont to Tennessee worked in numerous places.

"2. Deposits in the sandstones and associated trappean rocks, of the formation commonly called the New Red Sandstone; ores, carbonate, oxide and native copper, principally; contact deposits, usually of limited depth. Localities numerous in Connecticut and New Jersey; formerly extensively worked, but now abandoned.

"3. Veins traversing the new red sandsone and older metamorphic rocks, and bearing principally ores of copper in the sandstone. Locality confined to Montgomery and Chester Counties, Pennsylvania, and these extensively worked."

COPPER REGION OF LAKE SUPERIOR.

Attention was very early called to the remarkable deposits of native copper upon the shores of this great lake. The first mention of it appears to have been in the Missionary Reports of the Society of Jesus, for 1659–60. It is next spoken of by Claude Allouez, a Jesuit missionary, who visited this region in 1666. He speaks of having seen pieces of copper of ten or twenty pounds weight, which the savages reverenced as household gods, and of having passed the site of a great rock of copper, then buried in sand. In the Reports for 1669–70, Father Dablon reports a marvelous story,*

* They said that a party visited the Island, and in cooking their meals, observed that the stoves they used to heat the water were nearly all copper. They took plates of copper with them, and as they

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which was told him by the Indians, concerning a copper island about fifty leagues from the Saut, which he interprets as a cause of poisoning from the metal, loose pieces of which the savages used in cooking their meat. Charlevoix, whose travels were published in 1744, corroborates these accounts, and mentions the fact that a brother of the order made chandeliers, crosses and censers of the copper which was there found.

About 1763, a practical Englishman, Alexander Henry, passed through this region. He narrowly escaped being massacred by the Indians, but in spite of his trouble he kept his eyes open to his own interest. In 1771, he commenced mining operations in the clay bluffs, near the forks of the Ontonagon river. The following year he transferred his workmen to the vein on the north shore, but being discouraged by the contraction of the lode from four feet to four inches, he became disgusted and finally abandoned his workings.

In 1819, General Cass and Mr. H. R. Schoolcraft passed through this region and visited the famous mass of native copper on the Ontonagon. In 1823, Major Long and his party saw the scattered boulders of this formation. Nothing, however, came of all these observations, the general impression being that the wildness of the country and its distance from setlements rendered these enormous natural resources valueless, at at least for many years.

were pushing off from the shore, they heard a voice exclaiming, "Who are the thieves that carry off the cradles and toys of my children?" The whole party died, one shortly after reaching home, the others on their voyage.

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The first impulse to mining in this district was given by Dr. Douglass Houghton, state geologist of Michigan, who, in 1841, in his annual report to the Legislature, gave an account of the geology of the country, and the first scientific description of the copper deposits. Subsequently, he devised an admirable plan for developing the resources of this region, and had commenced carrying it into practice when his sudden death by drowning put a stop to these important observations.

In 1843 was ratified with the Chippewas a treaty, which put the United States in possession of the territory as far west as the Montreal river and southerly to the boundary of Wisconsin. The same year numbers of persons entered land in this neighborhood, by the provisions of a joint resolution of Congress in reference to the "lead lands" of Illinois, passed as far back as 1818. At first the applicant was allowed to select a tract three miles square, but afterwards he was limited to one mile square. He was required to make selection within a year, to mark the corners, to leave a person in charge to point out the bounds and to transmit to the proper department a description and plat of the same. On the receipt of this plat, the applicant was entitled to a lease of three years, renewable for three additional years, on condition that he should work the mines with due diligence and skill, and pay the federal government six per cent. of all the ores raised.

As a natural consequence of these liberal provisions, a great influx of speculators and their agents took place into this territory. The first mining operations were commenced in 1844. Masses of native copper

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containing silver were found, and numerous veins were discovered. About a thousand permits were granted by the department, and nine hundred and sixty-one sites selected. Sixty leases for tracts three miles square, and one hundred and seventeen for tracts one mile square, were granted, and mining companies were organized under them. "Most of the tracts covered by these were taken at random, and without any explorations whatever; indeed, a large portion of them were on rocks which do not contain any metalliferous veins at all, or in which the veins, when they do occur, are not found to be productive." The excitement reached its height in 1846. Quantities of stock were sold which represented no value whatever, and this reckless speculation injured the reputation of the mines.

In 1847, the country was almost deserted, only about half a dozen companies, out of all that had been formed, being engaged in mining.

In 1846, further grants of land were suspended as illegal, the resolution in regard to *lead* not covering *copper* lands, and the following year congress passed an act authorizing the sale of the lands and a geological survey. For the latter purpose, Dr. Charles T. Jackson was appointed, but after having spent two seasons in these explorations, he resigned, whereupon the work was confided to Messrs. Foster & Whitney, who have given a very full and satisfactory account of the geology of the country and its prospects as a mining region. Meanwhile, the actual miners had made considerable progress in their excavations, and as they purchased lands after thorough examination, confidence was gradu-

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ally restored. By the time the United States Survey had been completed and its results published, in 1850, copper mining had become an established business.

The report of Foster & Whitney contains some very interesting details of the discovery of ancient excavations for mining purposes. Some of these are quite extensive, reaching the depth of fifty feet, and containing rude implements for boiling water, stone hammers, copper gads and other mining tools. It would appear, from some of the indications, that fire was the agent used to disintegrate the rock. Some idea of the extent of their operations may be formed from the fact that one of the explorers found a mass of native copper, weighing six tons, which had been detached by these ancient miners and supported on billets of oak, preparatory to removal. The age of these works may be inferred from that of a pine-tree stump growing out of one of the mounds of rubbish from the mine. This contained three hundred and ninty-five annual rings, so that the exploration must have been made before Columbus started from Europe on his memorable voyage of discovery.

A rapid survey of the geology of this region forms a necessary prelude to any remarks upon its metalliferous veins. In this we follow Mr. Whitney.

Lake Superior lies in a basin of sandstone, belonging to the lower Silurian system, and believed to be the equivalent of the Potsdam sandstone, hitherto supposed to be the lowest fossiliferous rock in this country. The strata, on both sides, dip towards the centre of the lake. Going southward from any point between Saut Ste. Marie and the Pictured Rocks, the traveller passes over

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the upper members of the Silurian system, successively cropping out above the sandstone, with a slight southerly dip. Here the sandstone rock lies nearly horizontally, is coarse-grained, and but little coherent. Its whole thickness does not appear to exceed 300 or 400 feet. Where it comes in contact with the older azoic rocks, at about the Carp and Chocolate rivers, it rests unconformably upon them, being deposited nearly horizontally on their upturned edges. At Keweenaw Point, a peninsula extending from the southern shore, in a northeasterly direction for nearly seventy miles, the character of the rock changes. It becomes thicker, is tilted at a considerable angle, and is associated with great beds of conglomerate and trappean rock.

If this line of upheaval of trap be traced, it will be found to consist of a series of parallel ridges, usually two in number, but sometimes three or more, extending in a southwesterly direction along the whole line of the lake, at a distance of a few miles from it, gradually diminishing in elevation as they traverse Wisconsin, and disappearing before they reach the Mississippi. Their average height above the lake is 500 feet. Towards the south they present steep mural faces, while they dip at a moderate angle towards the north. This line, commonly known as the "Trap Range," for 120 miles in length and 26 in width, is metalliferous, along it occur the copper mines of the southern shore of Lake Superior.

The rocks of this range are various in character, but most of them are manifestly igneous, and are supposed to have been poured out at the same time that the depo-

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sition of the sandstone was going on. In the more elevated and central portion of the range, igneous rocks predominate, containing intercalated beds of conglomerate, of very inconsiderable thickness, between heavy masses of trappean rock. Upon the sides, the trap gradually thins out, while the conglomerate thickens, till in its turn it gives way to the sandstone. This system of bedded trap and interstitial conglomerate is very extensive, some of its beds acquiring a thickness of several thousand feet.

The usual mineral constituents of the trap are labradorite and augite, with a smaller proportion of other minerals, among which the most abundant are magnetic oxyd of iron, chlorite and epidote. The felspathic and augitic portions form a homogeneous paste, in which the other minerals are embedded, the difference in these rocks arising rather from their mechanical structure than their chemical composition. Thus on Keweenaw Point, there are two well-marked varieties of trap, between which are innumerable others partaking more or less of one or the other character. One of these is porous or vesicular in structure, containing cavities of various sizes, which have since the formation of the rock, been filled with other minerals. The other is very compact and finely crystalline. In the former or amygdaloidal variety, provided it be not too soft or porous, is found the largest amount of copper, the compact variety being unproductive.

The remarkable peculiarity of this region is the enormous quantity of native copper which is found in its veins. Elsewhere, native copper has been regarded as

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rather an accidental accompaniment of other ores, but here it constitutes the entire mass of the metallic contents, and this character does not change at the greatest depth which the workings have attained. Out of the bedded trap, however, sulphurets make their appearance. "Thus in the Bohemian or southern range of the Keweenaw Point, which seems to have been protruded at a late epoch, and under different conditions, and to have tilted up the system of bedded trap and interstratified conglomerate which lies to the north, the veins bear only sulphuret of copper; and on the north shore, where the trappean rocks are most developed, they appear to be of the same imbedded character, and they are traversed by powerful veins bearing the sulphurets of copper, zinc and lead."

The mines of Lake Superior are divided by Mr. Whitney into four groups: 1. Keweenaw Point; 2. Isle Royale; 3. Ontonagon; 4. Portage Lake.

Keweenaw Point contains a large number of mines, its mining region extending over a space about thirty-six miles long by two or three broad. From its eastern extremity a belt of metalliferous trap extends through it, in a nearly east and west direction, gradually curving in its western prolongation towards the south. There are two distinct ranges, the Greenstone and the Southern or Bohemian Range. The former comprises a line of bluffs, rising sharply from the valleys of Eagle and the Montreal rivers, which drain the district, rising near its centre, and flowing through it longitudinally in different directions. It is a compact, crystalline, homogeneous rock, several hundred feet thick, dipping to the

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north at an angle of twenty or thirty degrees. To the south, its limits are well defined. It rests upon a stratum of conglomerate, accompanied by a thin layer of consolidated volcanic ash, and below this lies the great southern metalliferous belt of Keweenaw Point. In this, numerous mines have been opened, which always fail in metallic contents when they are carried into the greenstone above the conglomerate and trappean ash.

At the eastern end of the Point, this bed of conglomerate is thirty or forty feet thick, but it gradually thins out, and finally disappears near the Cliff mine. The main features of the distinction between the greenstone and the amygdaloidal trap, however, remain. Between the conglomerate and the greenstone, towards the west, are occasionally found thin seams of quartz, which often contains sheets and particles of copper.

To the south of this thin belt of conglomerate, the amygdaloid extends for two or three miles; but as it lies in the low ground, it has only been explored by underground workings, which have not as yet penetrated its thickness, nor revealed the depth of the beds of which it is composed.

North of the conglomerate, the greenstone is from a quarter of a mile to half a mile wide, and gradually changes to amygdaloid resembling that on the southern side of the conglomerate. This "northern metalliferous amygdaloid belt" is bounded to the north by the sandstone, varies in width from a mile to a mile and a half, and contains several important mines, imbedded in a variety of trappean layers. Further north is a series of alternating belts of amygdaloid and sandstone of

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moderate thickness, varying from 50 to 500 feet; and next to these is a belt of conglomerate, nearly a mile wide. Beyond is another bed of amygdaloid rock, about 1500 feet thick, succeeded by conglomerate, which forms the northern portion of the Point from its extremity as far west as Agate Harbor.

The mines are worked, almost exclusively, in metalliferous deposits which have the character of true veins. They cross the belts of rock nearly at right angles, and have, in many instances, been traced through all the formations. One vein is known to have been worked on both sides of the greenstone. The veins change character as they pass through the different belts. In the conglomerate their gangues are calcareous, the copper being usually concentrated into large masses. In one instance, black oxyd of copper is found in the rock. Mr. Whitney thinks it probable that these same veins extend across the valley into the southern range, and there bear sulphurets.

In the true copper-bearing rocks, the veins are made up of quartzose rock, mixed with calcareous spar and zeolitic mineral, of which prehnite and laumonite are most common. The most favorable vein-stone contains crystallized and drusy quartz mixed with prehnite and granular carbonate of lime. In some instances the veins are brecciated, i. e. made up of fragments of the adjoining rock, cemented by the usual vein-stone. At other points purely calcareous veins have been worked in the trap, but they are now regarded as worthless, especially when the carbonate of lime occurs in the form of coarsely crystallized spar. Smaller veins or strings

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are made up almost entirely of laumonite, and contain very little copper.

"The width of the productive veins is usually from one to three feet; they sometimes widen out to ten feet or even more, but rarely continue to hold those dimensions for any considerable distance. The wider the vein, as a general rule, the richer it is in metallic contents."

But one system of veins has been observed in this district. They are remarkably regular in their course, which is nearly at right angles to the bearing of the formation. They are sometimes shifted a few feet to one side or the other, as they pass from one belt to another, but there are no regular cross-fractures or counter-lodes, such as prevail in most extensive metalliferous districts. The parallelism of the productive lodes of Keweenaw Point is very remarkable. They have no tendency to unite together.

The dip is nearly vertical, the underlay, or deviation from the perpendicular, being rarely more than eight or ten degrees. The vein is usually separated from the wall rock by a distinct selvage of red clay, and the walls are striated or polished. The copper is mixed with the vein-stone in pieces varying from the most minute specks and strings up to masses of one to two hundred tons weight. In accordance with the size of the pieces, the copper is classed under three varieties, mass copper, barrel-work and stamp-work.

Masses are sometimes met with twenty or thirty feet in length. In such cases the rock is cleared away from one side of the mass, and it is detached from the wall by heavy charges of powder inserted behind it. It is then

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cut up into pieces of convenient size for lifting through the shaft. This is a very tedious and costly process, several months being sometimes occupied in dividing and removing a single mass. For this purpose they employ chisels having a cutting edge of about the fourth of an inch in width, and varying in length according to the thickness of the mass to be divided. One man holds and guides the chisel, while another strikes it with a heavy sledge, so that chips are gradually taken out of a length equal to the distance to be cut across, and a thickness of about one-eighth of an inch. The process is repeated till the mass is completely severed. The expense of this operation is usually about six dollars for every square foot of surface exposed on one side of the cut. On reaching the surface, further subdivision is required, in order to obtain masses convenient for shipment. As thus prepared, the vein-stone not being entirely removed, the mass copper contains 70 or 80 per cent. of pure metal, though sometimes, being almost wholly free from foreign matter, it yields from 90 to 95 per cent. when smelted in the furnaces. This test, however, cannot be regarded as a satisfactory one of the actual amount of metal contained in these masses, since some of the smelting works are conducted in the most unscientific manner, and waste an enormous quantity of copper.

Barrel-work includes the smaller pieces, weighing usually a few pounds. This name is given to them because they are too small to be sent away without being previously packed in barrels. Much of this is obtained during the preparation of the stamp-work. The pieces are well hammered to free them from adhering vein-

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stone, and, as thus prepared, contain from 60 to 70 per cent. of pure copper.

Stamp-work forms a large portion of the yield of all the veins, so that each mine requires a set of stamps containing a number of heads proportioned to its extent. The rock is first calcined by being laid upon a pile of wood which is then kindled. Care is taken not to melt or oxydize the copper. The rock being thus rendered friable, is placed under the stamps. During this process of preparation, some pieces are met with which are too large to be put under the stamps, and contain too much copper to allow any further reduction in size. These are barreled up, and the rest of the ore is placed under the stamps, pounded, washed and packed up.

A full account of the mines in this region, beginning on the northern metalliferous belt, is given by Mr. Whitney, from whose valuable work we make the following abtract, supplying the later facts from recent authentic documents when we have been able to procure them.

The *New York and Michigan* mine was opened in 1846, and continued in 1847, till the shaft was 84 feet deep. It was then abandoned, resumed in 1852, when the shaft was continued. In September, 1853, having reached a depth of 150 feet, it was finally abandoned. A drift was run off to the north for 100 feet or or more, and the vein was found to be, in some places, 20 inches wide; the vein-stone being quartz and prehnite, carrying a little copper. Four small masses, weighing about 1,800 lbs. were shipped in 1852. This mine, being situated in the unproductive green-stone, could not be worked with profit.

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The *Clark Mining Company* commenced operations in the autumn of 1853, on a vein running north 10° west, a foot or eighteen inches wide, well filled with copper. It has been opened at several points, and found to be well defined and promising favorably for successful working.

The *Washington Mining Company* has several veins in the vicinity of Musquito Lake, but had not yet commenced operations at the date of Mr. Whitney's publication.

The *Agate Harbor Mining Company* has been exploring, and has discovered many powerful veins, having a course of about south 19° east.

Adjoining them is the "Keliher Vein," bearing north 25° west, being from two to eight feet wide, having a brecciated vein-stone containing much copper, and opened already over an extent of 2,500 feet.

The *Eagle Harbor Mining Company* has explored this region without success.

The *Native Copper Mining Company* commenced operations in 1852. A shaft had been sunk 120 feet and a cross-cut driven, at a depth of ten fathoms, to the vein. The vein is wide, brecciated and unproductive.

The *Copper Falls Mining Company* was originally formed in 1845. They began mining in 1846 on the "Old Copper Falls Vein." The workings were commenced upon a belt of trap only 170 feet thick, measured at right angles to the dip, and 430 feet across on the line of adit, inclosed between two beds of sandstone. A shaft was sunk 53 feet through the underlying sandstone. In the trap, the vein was rich, but on entering the

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sandstone, it rapidly contracted and split up so that it was not thought advisable to follow it. The shaft alluded to was therefore sunk and cross-cuts driven in each direction for forty feet, without finding the vein. The same vein has been traced on the surface, south of all the belts of sandstone. From this mine $15,000 worth of copper was taken, while on it $100,000 were spent. This resulted entirely from a want of proper geological knowledge. To remedy this defect, a competent geologist was employed, who surveyed the whole region and and discovered several veins, two of which, the Copper Falls and the Hill veins, have been worked. The first was opened in December, 1850, and the second a year later.

All these veins are nearly parallel, running north 22° to 25° west. In almost every instance they have been traced entirely across the whole belt of trap north of the greenstone. Upon each of these veins some shafts have been sunk, and large quantities of copper have been taken out. According to the report of the superintendent, dated March 1st 1854, it appears that they yield 865 pounds to the fathom.

The *Phœnix Mining Company* is the oldest of these organizations. It was formed in 1844, under the title of the "Lake Superior Copper Company." By direction of Dr. C. T. Jackson, work was commenced, in October, 1844, on Eagle river, and carried on through the year 1845. "A stamping mill and crushing wheels, of a kind suitable for grinding drugs, were erected but soon proved to be entirely unserviceable." Up to March 31, 1849, about $106,000 had been expended, "about

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half of which was probably for actual mining work." The principal shaft was sunk upon a "pocket" of copper and silver, without any signs of a regular vein, which soon gave out entirely. In 1846, a drift was run off from the shaft at a depth of ninety feet, towards the river, to find a vein, and directly under the river the workmen found a crevice, filled up with gravel. This was evidently the ancient bed of the Eagle River. Workings were carried on and a large pot-hole was found, filled with rounded pieces of native copper and silver. From this and other excavations, 18,000 pounds of copper were taken, as well as much silver, most of which was stolen by the miners. One piece of silver, weighing 96.8 ounces Troy, came in possession of the company. Finally the vein was struck and sunk upon for about ninety feet, after which work was suspended until the Phœnix Company took charge of the property in the autumn of 1850. This company continued operations along the vein, which still ran under the river, until February, 1853, when they abandoned it. The trouble from water, especially during freshets, was so great that it was impossible to work to any advantage and besides that, the vein, away from the river, was too narrow for profitable mining. The principal shaft was sunk to a depth of about 264 feet, and three levels driven between 500 and 600 feet. The vein-stone consisted of calc-spar with jasper and argillaceous matter and contained copper in fine particles and masses, some of which weighed 1200 pounds, together with silver.

In June, 1853, a thorough examination of the property was commenced, and finished in 1854. From

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Samuel W. Hill's report, dated January 5th, 1855, the following particulars are taken.

The property of the company is 1701 acres, having in its northwest part, the port of Eagle river. The land declines towards the Lake, its altitude rarely exceeding 550 feet above the level of the water, and averaging not more than 350 feet. The banks of Eagle river, (which runs through it,) vary in elevation, being, in some places high and precipitous, in others low and easily accessible.

The band of rock near the lake is conglomerate. It is succeeded to the southward by alternating beds of sandstone and trap, having a dip of 25° towards the lake. Below these are various beds of trap terminated by a hard, light blue columnar trap. Underneath this is a bed which is composed mostly of an ash, thin bands of trap and sand stone, and rounded scoriaceous bodies of trap or lava. This mass is cupriferous and between it and the stratum last named a slide has taken place. In some places the dislocation has been sufficiently great to produce open spaces between the walls, which have been filled up with vein-minerals. There are ancient excavations in this bed, and it is in some places well filled with copper. Below this is a greenish gray trap in which the principal excavations of the old mine were made. This is succeeded by several beds of trap, followed by a belt of crystalline trap or greenstone, the veins traversing which are well filled with copper. After this come several beds of trap, ending in a soft porous band, which overlies the series of dark colored, close-grained trap layers in which the Cliff mine is worked. After these

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comes a columnar trap, poor in copper, and then an amygdaloid which promises well for that metal.

These beds do not all contain copper. As elsewhere in this region, there are distinct metalliferous zones. The chief of these is the series worked in the Cliff mine. Next in importance is the ash or scoriaceous bed, which was at first thought remarkable for having the copper diffused through the rock and not in a vein. Subsequently, however, it has been stated that this scoriaceous bed is a true east and west vein.

There are several veins on this property, the Ward vein, the Forster vein, the Armstrong vein, the East Phœnix vein and several others which have not been named. The workings already described were upon the old Phœnix vein. Attempts were made to renew work on this vein in 1855, but finally discontinued on account of the old trouble with water. The Armstrong vein was worked in 1851 and 1852, but was found to be poor in copper. The East Phœnix vein was discovered in 1852 and the following season, a mass, weighing 2,390 pounds, was taken out quite near the surface. In 1855, the principal working was on the "ash bed." About five tons were sent to Boston in November of that year, and smelted at the Revere Works. The metal was found to contain a large amount of silver, the *poorest* specimens being reported as worth $100 a ton for that metal. The prospects of the company are now good.

The entire amount expended here cannot be much short of $200,000, and there are few places upon Lake Superior which show more abundant indications of copper.

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The mines on the southern side of the greenstone bluffs are very well situated for working. They have never been opened to any extent in the greenstone, but close to the conglomerate belt which divides the amygdaloid from that rock, they are as productive as anywhere else. In the neighborhood of the Cliff mine the position is less favorable for adit draining. Towards the eastern extremity of the Point, the amygdaloid rises sufficiently to give from one to two hundred feet of back above the adit level. Frequently the productive rock is so covered with drift that the veins can only be discovered by tracing them down from the greenstone and opening shode pits on their supposed course. This is the reason why so many ineffectual attempts were made to find productive veins in the greenstone and other more exposed rocks.

The *Keweenaw Point Copper and Silver Mining Company* was formed in England, and has discovered four or five veins, but has not worked them yet to any extent.

The *Star Mining Company* has sunk several shafts and abandoned them. During the summer of 1853, they discovered a new vein, which is said to promise well.

The *Manitou Mining Company* commenced operations in 1852. They have two veins, neither of them large nor very productive.

The *Iron City Mining Company* deserves notice here as a warning to future speculators on the minerals in this region. They have a wide and regular vein of calcareous spar, cleaving into large rhombohedra, and containing no copper. This kind of vein, when unaccom-

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panied by quartz and the zeolitic minerals, is always barren in the Lake Superior mining region.

The *Northwest Mining Company of Michigan*, being one of the most extensive, demands the special examination of those who are interested in the mineral developments of this district. In 1849, it took the place of a company which had been mining in a small way since 1847. They have three veins, the Stoutenburgh, Kelly and Hogan veins. The first contains the principal mine, and has a course of north 16½° east. The Hogan runs north 19° west, and the two would, consequently, intersect about 320 feet south of the mouth of the adit level on the Stoutenburgh. The third or Kelly vein has a course nearly parallel with that of the Hogan, but is not very well defined.

The first named vein has been opened by four shafts, the engine shaft being 500 feet deep. The longest level driven is about 1,000 feet. The whole amount excavated by sinking shafts is 1,130 feet; by driving levels, 5,450 feet; and the number of fathoms stoped is about 2,780. The vein is from six to eighteen inches wide, the average width being about a foot. The lode consists of clayey and sandy matter, with occasional strings of calc spar, and does not look very promising. It contains but a small amount of stamp-work and that of a poor quality, but masses, weighing from a few hundred pounds up to several tons are frequently met with. One of eleven tons weight was taken from the twenty fathom level. A great deal of that which is taken from the shaft is amygdaloidal trap containing shot copper; and it is worthy of remark that the rock in the vicinity of the vein is often richer in metal than the lode itself.

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The large masses appear to make outside of the lode but close to it, impoverishing it for some distance in every direction.

The works on the Hogan vein are much less extensive, but the vein is more promising, containing less argillaceous matter and being more crystalline. It has produced small masses and barrel-work as well as stamp-work.

This company is the only one that has kept accurate and reliable accounts of the produce of the stamps and the expenditures per ton. From this report, it appears that the average percentage of the rock when carried to the stamps is 1.34 of copper, so that a ton contains 27.4 pounds of copper. The entire cost of working, after the ground has been opened for stoping, is $4.42 per ton, and the value of a ton, after deducting expenses of transportation, is $6.97. Hitherto, however, the receipts of the mine have fallen short of its expenditures. The value of copper exported has lately averaged over $53,000 per annum, and the expenses $77,000.

We believe that this mine has now suspended operations.

The *Waterbury Mining Company* is another example of failure in consequence of want of knowledge of the laws which regulate the metallic deposits of Lake Superior. It was opened in a chloritic mass interposed between the conglomerate and the greenstone, and the contact of these last named rocks has never been found to yield copper in this region.

The *North Western Mining Company of Detroit*, works the same vein which on the opposite side of the crystalline trap is known as Copper Falls Vein. Its gangue is quartzose and chloritic, containing crystals of analcime

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and of reddish feldspar. Its average width is three feet. In the ten fathom level, a mass of copper twelve feet long and three feet high has been discovered.

The *Cliff Mine** is the most famous of all the workings on Lake Superior, being, indeed, the first mine in the United States, excepting those of coal and iron, which was extensively and systematically wrought. It is also the first mine ever opened in the world upon a vein bearing copper exclusively in the native state.

In 1843 a Mr. Raymond obtained several leases in this region, three of which he conveyed to parties in Pittsburg and Boston, who commenced mining in the summer of 1844. The first work was done in the autumn of 1844, upon the outcrop of a cupriferous vein at Copper Harbor, known to the *voyageurs* as the "green rock." On clearing away on the opposite side of the harbor, where Fort Wilkins now stands, numerous boulders of black oxyd of copper were found, evidently belonging to a vein near at hand, which was discovered in December, and proved to be a continuation of that worked during the summer.

Mining was commenced here immediately; two shafts were sunk 100 feet apart, and a goodly quantity of black oxyd of copper, mixed with silicate, was taken out. This was remarkable, as being the only known instance of a vein containing this as the principal ore. Unfortunately, this was but a rich bunch, which gave out at the depth of a few feet, although the vein continued. The gangue was chiefly calcareous spar, mixed with some argillaceous and quartzose matter. Fine crystals of analcime, as well as of native copper and the red

* Owned by the Pittsburg and Boston Mining Company.

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oxyd were found in it. About 30 or 40 tons of black oxyd were obtained and sold for $4,500. The main shaft was continued down 120 feet and levels driven each way, for a considerable distance, without finding another bunch of ore, so that in 1845 the company determined to explore their extensive property. In August, of that year, the Cliff Vein was discovered.

This vein was first observed on the summit and face of a bluff of crystalline trap, rising nearly 200 feet above the valley of Eagle River. The break or depression made by it in the back of the ridge was quite distinct, and has since been traced to the lake, and found marked by ancient excavations. At the summit of the bluff, it appeared to be a few inches wide, and contained native copper and specks of silver incrusted with capillary red oxyd. Half way down the cliff it had expanded to a width of over two feet, and consisted of numerous bunches of laumonite, with a small per centage of copper finely disseminated through it.

As the vein appeared to widen in its descent, by the direction of Mr. Whitney a shaft was sunk a few feet a little below the edge of the bluff, and a level driven into the greenstone for a short distance. Nothing of importance, however, was done till the talus at the base of the cliff was cleared away, and the vein traced into the amygdaloid. A level was then driven in upon it, and at a distance of 70 feet the first mass of copper was struck.

The beds of the rock dip at about 66° to the north, so that the extent of the mine in that direction, the vein being opened to the south of the greenstone, is continually increasing as each successive level is opened.

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To the south, the mine is limited by the extent of the company's property. The longest level, 244 feet below the adit had been extended at the date of Whitney's description, 600 feet to the south of the lower shaft, and the supposed distance to the greenstone is 900 feet. Each level extends in this direction about 100 feet further than the one 66 feet above.

The mine was formerly worked through two shafts, less than 100 feet apart; but during the winter of 1853–4, a third had been sunk to level No. 1, from the upper edge of the bluff, a distance of 138 feet. The engine-shaft, in 1854, had reached the ninth level, a depth of 444 feet below the adit, and the entire depth from the collar of the third shaft to the ninth level will be 630 feet.

"The remarkable and uniform richness of the vein may be inferred from the fact that no part of it is so poor as not to be worth taking down; and so far as the work has been carried, hardly a fathom of ground has been left standing on it. On calculating the number of fathoms of the vein removed in the drifts, shafts and stopes, I find it to be, approximately, 8,270; and there has been produced an average amount of 761 pounds of copper per fathom—a result which is truly astonishing, when it is considered that the *whole* of the vein has been taken down."*

It runs about north 27° west, and its underlay is about 10° to the east, but in its lower levels the dip varies somewhat. In some places it is three or four feet wide, in others, only a few inches; its average width is, probably from fifteen to eighteen inches. The vein-stone is

* Whitney's metallic wealth of the United States.

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quartz, calcareous spar, and the zeolitic minerals, and it abounds in fine crystallizations.

Its metallic contents are exclusively native copper and silver. The copper occurs in masses of great size, from a few hundred pounds up to nearly a hundred tons; and the vein is not only rich in these, but also furnishes a large quantity of stamp-work, containing an unusually high per centage of copper.

At the date of the last report, shaft No. 4, had reached a depth of 251 feet. The second shaft was sinking from the 70 to the 80 fathom level, at which it was expected to cut the vein. The extension of this shaft will be much deeper, if the productive stratum recently discovered at the North American mine be sought for. This will not be reached at a less depth than 950 feet from the adit level.

Besides this main vein, and its droppers, there are several others on the property. The *west* vein, which was formerly supposed to be a mere divergence of the old vein, upon one of its numerous floors of amygdaloid, has been found to be a distinct and separate lode, very rich in copper. The East Cliff vein, about 40 rods east of the present workings has been opened and seems to promise well. About 270 feet west of the main vein, there are surface indications of a very large lode, measuring from four to five feet in width. It is intended to open this by a cross cut from the 30 fathom level.

The operations of this mine will be seen by the following table, compiled from Whitney's book, and the printed reports of the Directors, the original amount of capital stock paid in by the Shareholders being only $110,905,00.

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DATE.	EXPENDED.	STUFF SHIPPED.	YIELD.		AMOUNT RECEIVED.	DIVIDENDS.	
		Pounds.	Per cent.	Amount Pounds.		Per Share.	Amount.
1844,	$ 3,066 76	—					
1845,	25,574 40	33,171	60	19,903	$ 2,968 70		
1846,	66,128 05	108,774	38.1	37,625	8,870 95		
1847,	89,409 16	729,848	56.3	410,783	70,977 32		
1848,	105,278 52	1,665,304	60.2	996,467	166,407 02		
1849,	106,968 77	2,285,050	56.1	1,282,127	155,227 04	$10 00	$60,000
1850,	118,784 14	1,521,391	46.9	714,643	177,044 36	14 00	83,825
1851,	127,623 51	1,528,465	55.3	846,486	174,931 96	10 00	59,915
1852,	112,929 81	1,660,330	49.9	829,356	161,917 08	10 00	59,885
1853,	.....	2,263,182	47.33	1,071,288	292,647 05	15 00	89,287
1854,	.....	2,332,614	56.35	1,315,308	320,783 01	18 00	107,744
1855,	256,553 23	2,995,837	62.56	1,874,197	475,911 26	13 00	76,871
1856,	.....	.....	.....	.....	.....	30 00	180,000

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The amount of silver taken out varies. It is always found in pockets, and never alloyed, to any extent, with the copper, even at the point of contact. The most usual mineral, accompanying the silver, is a greenish magnesian substance, apparently talc. In the Hill vein, a small quantity is found in the smelted copper a few ounces to the ton—not enough to justify its separation. At the Cliff mine, the largest quantity of this metal obtained in one year was nearly 35 pounds troy. It is picked out by hand from the coarse metal which is taken from under the stamp-heads.

The *North American* is another old company, and has mined extensively at two points. The "Old North American Mine" was opened in 1846, and worked till the spring of 1853, when it had reached the depth of 415 feet. The course of the principal vein is north 58° west, and, therefore, not parallel with the productive veins of the formation. During the four last years it was worked, it yielded 446,000 pounds of pure copper. The entire expenditures upon it were $200,000.

In 1852 this company opened the *South Cliff* mine, on an extension of the famous Cliff vein. Up to February of 1854, 715 feet had been opened in driving, 76 feet in cross-cutting, 438 feet in sinking in rock, and 106 fathoms had been stoped. From these workings the extraordinary amount of 506,000 pounds had been taken, yielding an average of 67¾ per cent. of copper.

At this mine, on the 4th of July, 1853, was thrown down the largest mass of native copper ever before found on Lake Superior. It was 40 feet long, 20 high, and 2 thick. Its weight was estimated at from 150 to 200 tons.

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The vein-stone of this mine, near the surface, furnished fine specimens of prehnite with crystallized copper. Its workings extend further south of the green-stone than those of any other mine of the region. At first the vein seemed to be impoverished in that direction, but as they advanced further, it began to improve.

The *Albion Mining Company* sunk a shaft on this point, in the same geological position as the Cliff Mine, to the depth of 200 feet, but finally abandoned their work for want of encouragement, in 1852.

The *Fulton Mining Company* commenced operations on an old working in 1853, and have taken out a great deal of copper. In one part of the mine, the vein yielded a ton of copper to the fathom. The vein-stone is remarkable for containing much epidote, mixed with calcareous spar.

In addition to the veins already explored or worked by companies, there have been others discovered upon this point. They are held by individuals, and have only been opened for exploration.

The geological character of ISLE ROYALE resembles that of Keweenaw Point. The ridges of trap traverse the island longitudinally, and this rock, with its intercalated conglomerate, forms the entire island. The strata dip in a direction opposite those on the point, and their mural faces look towards the north. The beds, however, differ from those in being thinner, so that the metalliferous veins are subject to frequent changes in passing from one stratum to another. Great hopes were formed of this island at the opening of the Lake Superior region, and soon afterwards nearly all of it had been taken up by different companies.

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The veins are differently situated with regard to the strata, some being at right angles and some parallel to their dip. Epidote belts, filled with fine particles of native copper, are found here, but they have not been found sufficiently persistent in metalliferous contents to be profitably worked. In 1853, nearly all the mines were abandoned, only two being wrought and those on a small scale.

The *Siskawit Mine* has been extensively worked, and was at first quite productive. On sinking but a short distance, however, a hard basaltic rock was encountered, in which the vein contracted to a mere fissure. After traversing this, the vein improved, but not sufficiently to pay for working it, especially as it was necessary to carry the workings under the lake, since the rocks dip in that direction.

The *Pittsburg and Isle Royale Mining Company* has worked a narrow vein rich in copper, which traverses a crystalline rock. Their machinery is "miserably defective," and their operations consequently impeded.

The ONTONAGON MINING DISTRICT receives its name from the principal river which drains it. This stream has three branches, one coming from the east, another from the west, and the third from the south. Uniting, they cross the Trap Range at right angles to its course.

The mines are on the range, and are worked at various points for a distance of twelve miles on each side of the river, making the entire length of the district about twenty-four miles. The cupriferous deposits here differ from those on Keweenaw Point in their being parallel to the line of strike of the formation.

The character of the trappean rocks also differs from

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that which they exhibit upon the point. The varieties of rock are more numerous and epidote almost always occurs where copper is found. West of the Ontonagon, a large part of the range on the north is made up of reddish quartzose porphyry, which appears to be entirely barren of copper. The layers of conglomerate are imbedded in the trap, and to the north it is flanked by heavy beds of this rock. There is no marked belt of unproductive crystalline rock here, and the position of the bed and veins, with regard to any fixed line of upheaval, is not so well ascertained. Copper is abundantly diffused through the district, but mining is not so profitable here on account of there being less concentration of the metal in limited spaces.

The copper occurs in four forms of deposite: 1. Indiscriminately scattered through the beds of trap. 2. In contact deposits between the trap and sandstone or conglomerate. 3. In seams and courses parallel with the bedding of the rock, and having the nature of segregated veins. 4. In true veins coinciding in direction with the beds of rock, but dipping at a different and usually a greater angle, in the same direction as the formation.

Deposits of the first class are common, and have been worked but with poor success. Masses of many hundred pounds weight have been repeatedly found in the trap, without any connection with a vein fissure, and sometimes unaccompanied by vein-stone. When smaller, the particles of metal usually fill amygdules in the rock, and are most abundant along the line of junction of two beds of different character.

Contact deposits have produced well in this district,

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though further working is requisite to test their permanent value. When they occur between the sandstone and the trap, they are not worth much, as they soon lose their metallic contents. The deposits which are found between the trap and the conglomerate appear to belong to this class, but have some of the features of true veins. In this position great masses of copper are accumulated near the surface, and even at considerable depths below it.

The third class of deposit, in segregated veins, is peculiar to this district. Occasionally the vein is irregular in its course, being suddenly heaved to one side or the other, or disappearing altogether. In these cases, the metallic matter seems to be accumulated in parallel courses, coinciding with the bedding of the rocks, but irregular in the extent and distribution of their metallic and mineral contents. Sometimes they run into each other, both horizontally and vertically, giving rise to the so-called feeder veins; frequently they diminish to a mere seam destitute of both veins and metal, and on cross-cutting another seam is struck, often well filled with copper.

The true veins are not numerous. They coincide with the line of bearing of the rocks, but in following them down, they are found to be wholly independent. They are often rich in copper, and may be confidently worked.

The *Douglass Houghton Mine* was worked on a small scale in 1846, but it was not till 1850 that it was prosecuted with any energy. The vein at the surface was between two and three feet wide, quartzose, and well filled

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with copper. There it had well defined walls with selvages of argillaceous matter, and a gangue distinct from the rock. On descending, however, it was found to be irregular, in some places wide and well charged with copper, in others entirely lost. There is a break or fault which has displaced it fourteen feet. In the winter of 1853–4, the vein had widened again.

The *Toltec Consolidated Mine* was opened in 1850, and up to March, the deepest shaft had been sunk 210 feet. Two levels have been driven and several cross-cuts made. A mass of a ton weight has been discovered, but the distribution of metal in the vein is so irregular that no conclusion can be formed as to the probable success of the mine.

The *Aztec Mining Company* have been carrying on excavations in the face of a bluff, which had been very extensively worked over by ancient miners. The copper is scattered indiscriminately through the rock, in lumps and small masses. In 1853 operations were suspended.

The *Bohemian Mining Company* works on what is called the "Piscataqua location." It is difficult to trace any regular vein here, but there is an epidote seam which is rich in copper.

The *Adventure Mining Company* has made many extensive but irregular excavations in the face of a bluff, in which there is no regular vein. It is a crystalline and compact trap having copper and silver scattered through it. In spite of the irregularity of the workings, a considerable quantity of copper has been taken out.

The *Minnesota Mine* is the most productive on the Ontonagon, and second only to the famous Cliff Vein.

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It was discovered in the winter of 1847–8, and found to contain excavations of the ancient miners, who had separated a mass of copper, weighing over six tons, and then abandoned it as too bulky for removal by the means at their command, leaving their stone hammers behind them.

Eight principal shafts have been opened on the vein and the South Lode, following its dip, which varies 52° to 64° to the north, that of the rocks being 44° in the same direction. The gangue is quartz, calcareous spar and epidote, and the walls well defined, although in some places not very regular. They are usually smooth, sometimes striated, but generally destitute of selvages and flucan. Near the walls, thin lenticular sheets of mixed calcareous spar and laumonite are frequently found overlapping one another.

The last printed report (March 1st, 1856,) states that, during the year, the shafts had been sunk in the aggregate 308 feet, and winzes to the amount of 418 feet opened, making the total depth of sinking in shafts and winzes on January 1st, 1856, 2516 feet. The deepest shaft, No. 2, had at that time reached the 60 fathom level, 447 feet from the surface. The extent of drifting for the same period was 3022 feet, the whole extent of the six levels on January 1st, being 10,728 feet. The longest level (No. 1) had been opened 1663 feet, the shortest (No. 5) 436 feet. These openings exposed about 117,642 superficial square feet of vein, on which the amount of stoping done was 15,912 feet, producing 890 lbs. of mineral per fathom, or about 148 lbs. per foot, stope measure.

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The whole extent of real estate owned by the company at that time (including 115 acres in suit between them and the National Mining Company,) was 2270 acres. During the year 1855, several masses were taken out, one of which weighing 5,738 lbs., was sent to England as a mineral curiosity. In the summer of that year, a mass of copper was exposed in the 10 fathom level near No. 5 shaft. In February, 1856, the agent reports that 27 men were constantly employed upon it, and that 200 tons of copper had been taken from it, but that they had not yet been able to determine its extent.

The following table is copied from the same report.

Date.	No. of men employed.	Expenditure.	Mineral product. Tons.	Nett value in copper.	Assessm'ts paid.	Dividends paid.
1848,	20	$14,000	6½	$1,700	$10,500	
1849,	60	28,000	52	14,000	16,500	
1850,	90	58,000	103	29,000	36,000	
1851,	175	88,000	307½	90,000	3,000	
1852,	212	108,000	520	196,000		$30,000
1853,	280	168,000	523	210,000		60,000
1854,	392	218,000	763	290,000		90,000
1855,	471	281,000	1,434	550,000		200,000*

The South Lode is at the junction of the trap with a bed of conglomerate, which crosses the Minnesota tract a short distance south of their main vein. They therefore opened it in 1852, by driving a cross cut from their adit level. Large masses of copper were found by the

* During this year the stock was increased to 20,000 shares, par value, $1,000,000.

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side of the conglomerate, whereupon a shaft was sunk in this neighborhood. The lode was found to be, in some places, five feet wide, and filled for a distance of 40 feet with a mass of copper almost continuous. Upon drifts the lode is very rich, carrying masses of copper interspersed with a good deal of silver.

The *Rockland Mining Company* is at work on lands which originally belonged to the Minnesota Company. It was formed in September 1853, with a capital stock of $500,000 in 20,000 shares, the terms of agreement with the Minnesota Company being, that the land should be put in at $100,000. It was, in fact, a dividend on Minnesota stock.

The tract belonging to the new company adjoins the Minnesota lands, and appears to carry across its entire breadth (some three thousand feet) a continuation of the veins just described. Some old openings were found, and explorations in these were so promising that the work was begun at that point. An adit was opened on the north side of the bluff. At a distance of 390 feet from the opening, it cut the north vein at the depth of 170 feet, and 230 feet further it lays open the main and the south lodes at about the same depth. At the date of the last printed report,* four shafts had been opened and sunk to a depth varying from 80 to 130 feet in depth, and a fifth had been commenced. Three levels had been opened, one 72 feet from the surface, the adit level on the vein, and one 10 fathoms below it. Besides this a cross cut had been driven from the adit, which reached the Minnesota South Lode, at the distance

* May 1st, 1856.

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of 275 feet from Rockland vein. Upon this drifts were made east and west, stripping the vein from the conglomerate which forms the foot wall. This vein is about two feet thick, and is said to be good "stamping lode." Barrel-work of from 10 to 20 pounds has been taken from it. At a distance of 100 feet south of the Rockland vein, this same cross-cut opened a large flat vein, from which pieces weighing from 50 to 100 pounds were taken. At shaft No. 4, a mass of copper, weighing 30 tons, and bearing unmistakable marks of the tools of the ancient miners, was found; from the adit level also, many masses have been taken, some of which weighed 15 tons.

This is considered one of the most promising mines on the lakes. The product of the first years operations was 23 tons, that of the second 137 tons of 70 per cent.

The *National Mining Company* in 1852, opened a vein lying between the conglomerate and trap, in the same range with, but at some distance from the Minnesota property. Ancient mine-work was discovered here, consisting of a shaft sunk to the depth of about 50 feet, timbered and scaffolded. A nearly continous sheet of copper extended down its side. Work was prosecuted vigorously during the following winter, and the next year 35,808 pounds of masses, and 46,046 of barrel-work, averaging 72 per cent. of pure copper, were shipped.

In January, 1854, 206 fathoms had been stoped, and 2,307 fathoms were ready for that operation. The vein is remarkable for lying between two dissimilar formations, and for containing scarcely any veinstone, being almost one solid sheet of copper for a considerable distance from the point at which it was first opened.

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The *Norwich Mining Company* has a regular vein of quartz, containing radiated epidote, native copper and red oxyd. The workings are extensive and the vein rich.

There are many other mines in this region besides those which we have noticed; but those we have named furnish the most instructive lessons upon the nature of veins and the prospects of mining in this vicinity. We have been somewhat full in regard to the particulars of these workings, but we do not feel that we have been unnecessarily prolix, as the Lake Superior region is so very important, the mines more extensively and scientifically worked than any of the same metal in our country, and much misunderstanding prevails concerning them.

Of the PORTAGE LAKE mining district we have little to say. The mines are not fully developed; there are few, if any, regular veins, the metal being found disseminated through beds which run with the formation, and differ but little from the other trappean beds with which they are associated. They are more regular in their course, and more uniform in their contents, than similar deposits on the Ontonagon River. Ancient excavations have also been found extending over a great length of vein.

The great value of the Lake Superior district, as a mining region, may be gathered from Mr. Whitney's table of the yield of the more important mines. From this it appears that from 1845, when the first casual excavations were made, up to the close of 1853, 4,824 tons of pure copper had been taken from these mines, and considerably more than one-fourth of this total had

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been sent off in 1853. At the date of publication of his book on the Metallic Wealth of the United States, there were 75 mines at work, employing 2,800 men. The entire amount expended upon the whole region, up to December 31st, 1853, he estimates at $4,800,000; and the value of copper produced, at an average price of 25 cents a pound, was $2,700,000. Of this, $504,000 had been paid out in dividends, and the rest applied to the further development of the mines. Of the capital, a considerable portion was invested in mines which promise remarkably well, but which had just been opened at the time the above estimate was made; a great deal of it, however, was thrown away during the wild excitement which characterized the first reckless speculations in this district. The mines are permanent, and whatever may be the fluctuation in the market prices of the stock of individual companies, there can be no doubt of the great value of the veins of the region. The yield for 1854 was estimated by Mr. Whitney at 2,000 tons of pure copper.

The trap range extends into Wisconsin, but no valuable veins of copper have yet been discovered beyond the borders of the State of Michigan.

On the northern shore of the lake, in Canada, numerous companies have been formed and have attempted mining in the trappean rocks, as well as in those of the azoic period. The trap appears to correspond with that of the south range on Keweenaw Point. No workings are now going on here, but from 1846 to 1849, a powerful vein was wrought on Spar Island and the main land opposite. The copper occurs in the form of pyrites and

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variegated sulphuret, but the ore is too small in quantity to be worked. Native silver and sulphuret of zinc have been found in the vein on the mainland.

On Michipicoten Island, in 1846, operations were commenced by the Quebec and Lake Superior Mining Association. Formidable preparations were made. An adit was driven 200 feet, three shafts sunk, a level commenced, and smelting furnaces erected. At last, after expending $150,000, they discovered that there was no ore to smelt.

On the north shore of Lake Huron, veins are found in a white sandstone or quartz rock, containing sulphurets, chiefly pyrites. The Bruce Mine is situated about fifty miles south of Saut Ste. Marie, and has been successfully worked. During the first year an open cut, 126 feet long and 5 deep, was made, from which 240 tons of ore were taken. After this shafts were sunk, smelting works erected, and a great deal of money wasted on unprofitable improvements. In spite of this bad management, however, the mine pays a good dividend, and is likely to do still better.

ORES OF THE MISSISSIPPI VALLEY.

In the Mississippi Valley, numerous cupriferous deposits occur at the junction of the lower Silurian limestone with the azoic rocks. They are often found in connection with the lead ores of the west, which they resemble in their mode of occurrence.

In Wisconsin, these ores lie far to the south of the trappean rocks. They occur chiefly in the neighborhood of Mineral Point, in what is called the Ansley

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Tract. At that place the ore occupies a fissure in the limestone 14 feet wide at the surface, and traced for a quarter of a mile. For a depth of 15 feet, the fissure is filled with weathered rock or gossan, as it is commonly called, together with lumps of sulphuret and carbonate of copper. Below that depth is clay with a little ore scattered through it. About a million and a half pounds were taken from this fissure, fifty thousand of which were sent to England with the effect of bringing the shippers in debt. As the underlying sandstone is only 100 feet from the surface, and as it is probable that the ore will fail there, the deposit cannot be regarded as valuable.

In Missouri, the copper ores also lie in Silurian rocks, resting in basins of the older rocks, the principal of which are granite and porphyry. The Mine La Motte has a celebrity, according to Mr. Whitney, far beyond its actual value. The property includes 24,000 acres, and contains numerous so-called mines. The most steadily wrought of these is the Philadelphia mine. Here the sandstone and limestone rest on the granite. The metalliferous deposit is a bed lying between a stratum of sandstone and another of hard crystalline limestone. It is a slaty mass, from 12 to 18 inches wide, containing galena in flat sheets, and pulverulent ores of cobalt and nickel. The copper pyrites occurs in fissures in the limestone, disseminated through a thickness of six or eight feet. This metalliferous stratum forms a lenticular mass, dipping at small angles in every direction from the centre, and appearing to be several hundred feet in diameter. Mr. Whitney thought the mine worthless.

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He does not appear to have formed a more favorable opinion of the other mines in the same State, which resemble somewhat the Mine La Motte.

ORES OF THE ATLANTIC STATES.

Ores of copper occur abundantly in the metamorphic rocks, or crystalline schists and associated igneous masses which extend along the eastern slope of the Appalachian chain, from Vermont to Georgia. Mr. Whitney says in reference to them:

"These deposits, wherever examined, are found to bear a striking similarity to each other; they are never found occurring in well-developed transverse or fissure-veins; or at least, such has never come under my observation. They all form masses parallel with the formation and possessing all the characteristics of segregated veins; or if, as is occasionally the case, apparently crossing the strata at an angle, such branches will be found subordinate to segregated masses, and not exhibiting, in an unmistakable manner, the phenomena of fissure-veins. The ores thus occurring are almost always pyritous, with, occasionally, a small portion of the variegated; and they do not usually appear to be oxydized to any considerable depth from the surface. Sometimes specular and magnetic oxyds of iron form the outcrop of the vein, and are replaced to a greater or less extent beneath by ores of copper. On the southwestern side of the Appalachian chain, in Tennessee, this decomposition and the formation of gossan has, however, taken place on a large scale; in other respects the deposits of the

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ores are similar to those of the eastern slope, except that they are on a scale of greater magnitude."

MAINE.—There are a few quartz veins, carrying copper pyrites, in this State, but nothing worthy of attention.

NEW HAMPSHIRE.—There are numerous localities of copper pyrites in this State, but none of them have, as yet, been worked to any extent.

Dr. Jackson, in his Report on the Geology of New Hampshire, mentions several towns as containing ores of copper, but condemns the majority of them as being in too small quantity for profitable working. Of two, he speaks favorably—one in the town of Bath, the other in Warren.

At Warren, there is a remarkable bed of tremolite, forty-eight feet wide, between walls of mica slate, which is impregnated with copper pyrites. It is also mixed with blende, galena, iron pyrites, and a little rutile. There are also several quartz veins on the property, one of which carries lead, copper, and zinc, the predominant ore being argentiferous galena. At the time of my visit, late in 1856, there were two shafts—one in the tremolite bed, the other in the quartz vein. A few tons of ore had been taken out, chiefly from the upper shaft, or that sunk in the quartz. The tremolite is soft and easily crushed, and though it is not a regular vein, yet its great extent may enable it to be profitably worked. It is also quite possible that, on further exploration, veins may be found cutting it, in which case it might be expected that they would be enriched as they traversed it. There are, in this neighborhood, small

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veins which cross the direction of the strata. The whole region would justify a more extensive exploration. Preparations are now being made to work the mine for both lead and copper.

At Unity, on the farm of James Neal, is a vein of iron and copper pyrites, one to three feet wide, running with the stratification, which has been traced for two thousand feet. Whitney reports the ore as yielding 12 per cent., and speaks encouragingly of the locality.

VERMONT.—Several localities of copper pyrites exist in this State. At one of them, in Corinth, some openings have been made, from which ore has been sent to the Revere Copper Works, at Boston. At Strafford, in 1829, a furnace was built for the purpose of smelting the copper pyrites which occur there, mixed with iron, but the attempt did not succeed.

MASSACHUSETTS.—A little pyrites and erubescite has been found in this State, in veins which have been worked for lead—in Northampton and Southampton—but not in sufficient quantity for mining.

CONNECTICUT.—There is quite an extensive copper mine at Bristol, which was first worked in 1836. It is a contact deposit, at the junction of the sandstone of the Connecticut River Valley with the older metamorphic rocks. The linear extent of metalliferous ground is eleven hundred feet. The mine is opened, to the depth of forty fathoms, by an engine shaft, which, at the date of the Report of Professors Silliman and Whitney, (August, 1855,) was the only working shaft. The width of the ore ground, from east to west, (the deposit running N. E. and S. W.) is one hundred and twenty

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feet, a width which is maintained on descending. Till recently, the workings were confined to micaceous and hornblende slates, sometimes passing into gneiss, and including large irregular "horses" of granite, which rock appears to have formed segregated masses, lying rudely parallel with the bedding of the schistose rocks. The strike and dip of these, however, is found throughout the mine to be very irregular, and there is evidence in the confused character of the ground, as well as in the slip joints and polished surfaces of the rocks, that motion of the various beds upon one another has taken place along lines of limited extent and varying direction. The distribution of the ores in the metalliferous ground now under consideration, is found to be as irregular as is the structure of the ground itself. They consist principally of the vitreous, with some variegated ore, and a comparatively small amount of copper pyrites. In general, these ores are found occurring in bunches and strings, which, though preserving, usually, an approximate parallelism to the line of contact of the formations, cannot be traced continuously for any considerable distance. Hence the irregularity of the workings, especially in the upper levels, which have been extended in upon various bunches of ore, or in search of others supposed to exist in certain directions, without any particular system or previously concerted plan. This has been the greatest drawback on the prosperity of the mine, since the ore ground was too wide to be all taken down by the miners, and the distribution of the bunches of ore in it was too irregular to admit of their being found without occasional

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expensive excavations in dead ground. In general, throughout the mine, a tendency to a concentration of ore around the masses of granite may be remarked, and the latter are not unfrequently well filled with strings and bunches of ore, especially near their exterior.

"The limits of the ore ground, to the west, or in the direction of the older rocks, the sandstone being to the east of the contact line, have never been well ascertained, and must be somewhat irregular, as would be expected from the nature of the deposit." One of the levels going north from the twenty fathom cross cut, has been driven along a regular wall, dipping easterly at an angle of 62°, found also in the thirty fathom level, but traceable in neither, more than one or two hundred feet. Within this ore ground, the average distribution of copper is very uniform. Between the sandstone and this metalliferous belt, lies a soft talco-micaceous slate, with bands and nodules of harder rock, called the "great fluckan." It is twenty-seven feet wide in the twenty fathom level, but gradually increases as it descends, till at fifty fathoms deep it has attained a width of fifty feet. The authors of the report do not expect that it will continue to widen indefinitely, but regard it as a lenticular mass, which will narrow again. It contains vitreous ore disseminated through it in small particles, and occasionally concentrated into strings and bunches of considerable size. It has so far yielded, on stamping and washing, over three per cent. of ore, containing thirty per cent. of copper. It is so soft as not to require blasting, and when exposed to air and moisture, disintegrates to a fine clay. Besides these deposits, a seam of

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ore has been cut in the sandstone, not far from the flucan.

The mine was opened in 1836, and though frequently changing owners in the following years, produced ores which were chiefly sent to England. It was not till 1847, that it was worked to any considerable extent. Since then, over 1800 tons of ore have been taken out and sent to market. It is a favourite ore with smelters, not only on account of its composition but of the admirably uniform manner in which it is dressed. The yield varies with the character of the ore. I have made numerous analyses of samples of cargoes and have found none of lower yield than 18 per cent. of copper, while some gave over 50 per cent.

Copper has been found associated with the lead at the different localities of that metal in this State, but as yet in no important quantity.

NEW YORK.—There are plenty of mineralogical copper localities in this State, but none sufficiently important to justify mining operations for that metal alone. At the Ulster Lead Mine, copper pyrites has been found in sufficient quantity to render it worthy of attention and separation from the lead.

PENNSYLVANIA.—The principal mines in this State are in the new red sandstone and will consequently be noticed under that head. Those in the older rocks have so far not been profitable. The Gap Mine, in Lancaster county, is the oldest of these. It was first opened in 1732, and afterwards taken up by another company which made large expenditures, but it has never paid.*

* Recently it has been worked for nickel, and copper ore of about 10 per cent. has been obtained as a secondary product.

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Near Pottstown, at the St. Peter's mine, a shaft has been sunk cutting a vein of calcareous spar, containing blende and copper pyrites.

MARYLAND.—A number of mines have been opened in this State and a few are still in operation. In Frederick county, near Liberty, work was carried on for some time, but finally abandoned. Attention was then turned to the New London mine, in which a shaft was sunk and levels driven by Isaac Tyson, Jr., who worked it for a while and then gave it up.

Dolly Hide Mine, in the same neighborhood, held out for a time stronger hopes of success. It was worked in a broad band of crystalline limestone, which, in some places, is 100 feet thick, containing numerous parallel layers of ore, mixed with quartzose matter, colored brown by iron, manganese and copper. It also contains a "black dirt" which is a product of decomposition, having variable quantities of black oxide of manganese, mixed with copper and iron. The copper ore when not decomposed is chiefly erubescite, mixed with pyrites, the latter usually scattered in minute specks through the former. Some masses of malachite, chiefly botryoidal, of considerable size, have been taken from this mine.

Work was carried on irregularly, at intervals, up to 1846, when it was leased to Isaac Tyson, Jr., who carried it on for several years. Finally a stock company was formed, with a capital of $600,000. They worked it but a short time before they abandoned it. The deposits, though extensive, are too uncertain and irregular to justify large outlay and they cannot be worked without it. There is no likelihood at present that work there will be resumed.

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The yield of the mine from 1842 up to May 1843 is stated, in the published reports, to have been 191,933 pounds of ore averaging 22 13-32 per cent. and 127 tons of "black dirt" averaging $10\frac{5}{8}$ per cent. of copper.

In the neighborhood of Sykesville, there is another metalliferous belt, occurring among talcose, chloritic and hornblende slates, the veins being parallel with the formation. Of these, the most important is the Springfield mine.

Springfield Mine.—This mine was originally opened by the Messrs. Tyson for iron, and afterwards worked for copper. It is about a mile from the Sykesville station of the Baltimore and Ohio Railroad and 32 miles from the city of Baltimore. It lies among slates which are micaceous, talcose or chloritic; the talcose slate closely resembling that of the gold regions of Virginia and North Carolina. Gold has been found in small quantity in the iron ores of the neighborhood. The vein is parallel with the stratification of the slates and dips with them, its general direction being about north 30° east; south 30° west, and the dip nearly vertical. On the surface there is a very powerful outcrop of a quartz rock impregnated with specular and magnetic oxides of iron in small granules. The same rock makes its appearance at the shallow openings along the line of vein, wherever the surface soil has been penetrated. A little deeper, the oxides of iron become sufficiently concentrated to justify working, and accordingly the upper levels have been stripped for the use of the neighboring Elba furnace. Still lower are found carbonates and silicates of copper, which are soon replaced by copper pyrites.

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The vein has been opened by an engine shaft, which at the depth of 66 feet, is cut by an adit level, 500 feet long, provided with a tram road for the removal of ore. At the time of my visit, in February, 1857, four levels had been driven and some stoping done. The vein thus exposed, has distinct walls and selvages. In the forty-five fathom level, there is a "horse" and a "slide" descending at an angle of 45 degrees. In the neighborhood of these, there are concentrations of yellow ore about four feet in thickness. A new shaft, inclined at the angle of the slide has been made, and it serves the double purpose of opening the mine more thoroughly, at the same time that it ventilates it.

This mine is steadily increasing in productiveness and the ores enriching as they descend. During the year ending April 1st, 1857, 300 tons valued at $17,896.92 were mined and sent to market. The report to the stockholders bearing that date, estimates the present capabilities of the mine at 50 tons a month, and expresses the belief that in the following October, it will reach 125 tons a month, owing to the greater amount of ground which will be opened, and especially to the sinking of a new shaft upon a vein of erubescite recently leased. The ore of the old vein is yellow pyrites mixed with magnetic and specular iron. The last lot sent to the Baltimore market (December 1857,) contained 16.03 per cent. of pure copper. Some nickel and cobalt are found in this mine.

The company is chartered in Maryland; the number of shares being 100,000, at a par value of $5 per share.

Mineral Hill Mine is six miles northeast of Sykes-

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ville. There are four veins, parallel with each other, running north 15° east, in a talcose and chloritic slate. One of them appears to be a fahlband of slate, impregnated with copper pyrites and small bunches of cobalt ore. The three others carry, at their outcrops, magnetic and specular iron with traces of gold; and, as in Springfield, these gradually give place to copper pyrites and erubescite in the deeper workings.

There are three shafts, from which some ore has been taken.

Patapsco Mines.—This is owned by a Philadelphia company. It was originally worked in a heavy bed of soft iron ore, containing very handsome specimens of fibrous malachite and some copper pyrites. In the deeper workings more copper pyrites was found, which was gradually substituted by cobalt. The mine proved unprofitable.

Bare Hill Mine.—The mine is about seven miles from the city of Baltimore. Although irregularly worked, a good deal of ore has been taken from it. These ores are pyritous, interspersed with chromic, magnetic and specular iron. The mine has been idle for several years, on account of law-suits respecting its title.

VIRGINIA.—In many parts of this State copper is found; often native in sheets lining the joints of the epidotic trap rocks of the Blue Ridge and in threads penetrating them; and sometimes in the form of copper pyrites, erubescite, red oxide of copper, &c.

Manassas Gap Mine.—At Manassas Gap, in Fauquier county, there are some remarkable deposits of copper. They consist chiefly of the oxides of that metal

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embedded in igneous rocks, though there are also veins of pyrites on the land. There are two groups of veins imbedded in slates which have a nearly vertical dip. The first group is composed of pyrites veins, parallel with each other and with the formation; the other consists of veins containing oxide and native copper and running in different directions. One has a course of north 30° east, parallel with the strike of the slates; the other runs north 70° east. This cross vein had, at the time of my first visit, been cut in a shallow trench, dignified by the name of a trial shaft. In that, it appeared to be from 10 to 12 feet thick, and to dip at an angle of about 62°. At the time of my second visit, work had been commenced. An adit had been cut in the side of the hill, towards the veins, with the intention of reaching them at a point where they were supposed to intersect. In this adit another vein had been cut. A shaft had also been sunk away from the vein and a gallery driven through dead rock in the hope of reaching the vein again. These openings were expensive and unprofitable. The vein would have been proved in a more economical way by sinking an inclined shaft upon it, and then, if found to continue as it had begun, more extensive openings might have been made.

The mine has, I believe, been abandoned. Nothing could have been better, however, than the surface ore. I analyzed several samples of it, and think fifty per cent. to be a moderate computation for the average yield. The vein-rock itself contained over two per cent. of copper.

In Nelson County on the Blue Ridge, not far from

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Rock Fish Gap, there is a powerful quartz lode containing copper pyrites. It has never been worked to my knowledge.

In Albemarle, at the Faber lead mine, copper pyrites also occurs, together with galena, and blende or sulphuret of zinc.

The principal copper region of the State is in the south-western part, in the counties of Carroll, Floyd and Grayson. Here the slates of the Blue Ridge approach the limestones of the Alleghanies, and the two ranges of mountains become blended with one another, the general trend of both being north-east and south-west. The district is on the south-western slope of the Blue Ridge, about twenty-five miles from a railroad. The geological structure of the country consists of slates, chiefly micaceous and talcose, with some conglomerates, underlaid, according to Dr. Dickerson's report, "with a fine-grained, compact hornblende and felspar, analogous to green stone." Among these shales lies a broad metalliferous belt, continuous, it is believed, with the great cupriferous deposits at Ducktown, Tennessee, traceable by an outcrop of gossan for three hundred and sixty miles. Within this belt are found several distinct beds of ore, the outcrops of which are known by the name of "leads." Dr. Dickerson names five of these, the Early, Dalton, Dickerson, Toncray and Native leads, and says that he has heard of others, but did not see them. These belts of ore follow, to some extent, the direction of the bluffs upon which they occur. "Seams of white quartz, interlaid with chloritic greenstone, forming small feeders, often occur, and invariably carry"

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copper ore. At such points, the direction of the lead is N. 45° E. The width of these leads varies from 114 to 32 feet. Immediately under the gossan, a much decomposed smut ore occurs in a greatly altered rock, so soft that it can be removed by the pick alone. It is a mixture of red oxide with sulphuret of copper, and with oxide and sulphuret of iron. Below this, lies an iron pyrites intimately mixed with quartz, which is known here as arsenical iron, though there does not appear to be any arsenic in it. From the description in Dr. Dickerson's report, it would seem that these cupriferous deposits are in the form of lenticular masses, the result of decomposition of the underlying mass. He informs us that the body of ore is thicker in the valley, and that where the copper ore lies high, the dip of the so-called arsenical iron is but slight, whereas when it is deeper, the dip is steeper. The depth of this underlying mundic is not known, as it has not been penetrated deeper than four feet. The workings for the examination of these copper deposits have been chiefly horizontal galleries, driven in from the sides of the hills along the course of the lead, and cross cuttings made at various elevations in the east flank of the mountains.

There are numerous workings along the lines of these leads, but it is not easy to get information concerning them. The oldest of these is the *Cranberry Mine.* "The property contains one hundred acres, and extends half a mile on the lead. Two shafts had been sunk on the south end of the lead, below the summit of the bluffs, which proved the lode upwards of 600 feet. From the side of the hill a horizontal gallery was driven,

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on a course of 45° E. of N., and extended upwards of 400 feet, giving an average width of seventeen feet of copper ore. The south wall is well defined, being composed of a talco-micaceous slate, containing now and then small patches of garnets of beautiful form and color. Numerous small vugs occur in this gallery, many of which are filled with the finest crystalline forms of ore." The ore is taken out of variable richness. Dr. Dickerson speaks of having seen masses of oxide weighing more than a ton, and containing sixty per cent. of metallic copper.

There are twelve or fourteen openings in this great metalliferous belt, worked mostly by companies organized on the copartnership system.

The *Cranberry Mine* is one of the oldest of these openings. Its property contains a hundred acres, and extends half a mile upon the lead. At the date of Dr. Dickerson's report, two shafts had been sunk below the summit of the bluffs. From the side of the hill a horizontal gallery had been driven for over 400 feet, cutting copper ore of an average width of seventeen feet. A hundred feet from the opening, streaks of flucan were discovered, and near them a large deposit of red oxide of copper. The south wall is well defined, consisting of talco-micaceous slate containing fine garnets. In this gallery are numerous vugs, many of which are filled with fine crystals. The ore bed is composed of two distinct layers, the upper containing the best ore. The average percentage of the ores taken from this mine is set down at 26·43.

The *Wild Cat Mine* adjoins the Cranberry on the

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West, its openings being made upon both the Early and the Dalton leads. The property contains three hundred and fifty acres, and is seventeen miles from Mack's Meadows, a station on the Virginia and Tennessee railroad, with which it is connected by a good turnpike road. It extends half a mile on either lead. Mining was commenced here in February 1855, by an open cut, from which a gallery was driven into the hill. The geological features of this mine are the same as those of the last described. The veins in the valley dip more perpendicularly, and are considered richer. The north wall is well defined, and filled with small garnets.

The *Ann Phipps Mine* is next to the West, owning a property of a hundred and forty miles, extending a mile upon the Early lead. Work was commenced late in March, 1855. According to Mr. Richardson's letter in the London Mining Journal, the channel of mineralized ground on this estate is one hundred feet thick, containing a champion lode eight feet thick, on a foot wall of mica slate, having an underlie of 55° S. E., and a range, as traced by out-croppings, of 50° N. of E., which will probably change to 35° in the deep workings. The country and hanging wall are composed of mica and clay slate with garnets. The matrix is quartz and iron pyrites. In the higher levels, there is much gossan and decomposed slate. There is also a strong flucan on the foot wall. On the surface there is much bright gossan, impregnated with grey and black ore, the branches of the lode. At thirty-five feet below, these concentrate, and a solid mundick is reached, filled with yellow and grey ore. Of the yield of this mine, I have no statistics.

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The *Dalton Mine* is three-fourths of a mile south-east of the Ann Phipps. The shaft, according to Mr. Richardson, is sunk in a ravine, penetrating twenty feet into the lode, and twelve into solid mundick. As usual, upon the surface, there is gossan. The quartz vein, twelve feet thick, contains eight per cent. of yellow copper.

Of the other mines in this region, I have no reliable information.

North Carolina.—There are a number of copper mines in this State, none of which have, as yet, produced a great deal of ore, though many of them look very promising. Copper is certainly very widely distributed through the state. In the north-western corner, at Ore Knob, in Ashe County, a mine has been worked for several years, and has produced some excellent yellow ore. This appears to be in the same range with the mines in south-western Virginia. Following the same line down along the Eastern slope of the Unaka, Smoky, and other mountains dividing Tennessee from North Carolina, there are numerous deposits of copper. On my visit to that region, in December, 1855, there was much excitement in regard to ores of this metal, and numerous openings had been made, but too imperfect to enable any one to arrive at any definite conclusions in reference to the matter. In the south-western part of the State, on both sides of the Blue Ridge, among the micaceous and talcose slates, there were evidences of the presence of copper, and at numerous points upon the creeks in Macon and Jackson counties, yellow and grey ore of fine quality had been taken out

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in small quantities. It is my impression that this region will, on proper exploration, be found to contain not a little metallic wealth.

An important region for gold, silver, copper and lead, exists in the centre of the State, occupying the counties of Guilford, Cabarras, Mecklenburgh and Davidson.

North Carolina Copper Company.—The mine worked by this company is about nine miles from Greensboro' in Guilford County. It was formerly worked for gold, and known as the Fentress or Stith's Mine. In 1852, it was purchased by a New York Company, and by them it has been worked for copper only. The cupriferous deposit has a direction parallel with that of the slates in which it is enclosed, about N. 30° E.; its dip, which, at the surface, is only 15°, gradually increases; and is, at seventy feet in perpendicular depth, about 45°. The ore is almost solely pyritous copper, associated with some sulphuret of iron. It is said, on good authority, that there is a large quantity of ore exposed, but the work has thus far been conducted with an entire want of judgment, the only aim seeming to be to raise as much ore immediately, without regard to the future of the mine. At the time of the publication of Whitney's metallic wealth of the United States, to which I am indebted for the above information, it was reported by the parties interested, that they were raising one hundred tons of twenty-five per cent. ore monthly. I have been able to get no further information, except that the company intend erecting smelting furnaces for separating the metallic from the earthy parts of the ore.

In most of the old gold mines, copper pyrites is found,

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and much of this ore has accumulated from the gold workings. Some of them are now worked conjointly for both metals, and the opinion of those who have had opportunities of judging, is, that they will prove valuable for copper.* At the McCullock Mine, in Guilford County, the copper ore is found in a layer of quartz, overlying iron pyrites, the gold being underneath both.

TENNESSEE.—Following the range of mountains between this State and North Carolina, from the Virginia frontier, the explorer finds copper in different localities. Imperfect explorations have been made at various points on this range, without any satisfactory result, so far as I have been able to learn, except in the extreme southeastern portion of the State. There, in Polk County, on the Ocoee River, is a very remarkable deposit of copper, which has attracted no little attention, and sent a good quantity of ore to market.

The region in which these ores occur is an old Indian province, known by the name of Ducktown. It is an elevated basin or trough, lying between the Unaka and the Blue Ridge, about a thousand feet above the level of the valley of East Tennessee. The country is cut up into knolls and ridges of tolerably uniform height, and the district is traversed by the Ocoee River, a tributary of the

* In a private letter to the author, Dr. F. A. Genth says of the mines of this region: "As a general thing, all true veins, *i. e.*, such as intersect the strata, and are not merely metalliferous strata of the formation, apparently will turn to copper veins at a greater depth. They contain generally less gold near the surface, rarely averaging more than fifty per cent. per bushel, but at and below the water level, the indications of copper appear, and become stronger with every foot sinking.

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Tennessee. The geological formation is made up of micaceous and talcose slates, with some hornblende, dipping at a high angle towards the south-east, and running N. 20° E. These are crossed by quartz veins, but the great metalliferous beds are parallel with one another and the strike of the strata. At the time of Whitney's visit, there were but two of these known, and upon only one of them had any important openings been made, but Prof. Safford, the Geologist of the State, writing in 1856, speaks of *seven* or *eight* distinct veins, the course of six of which, he figures on his map.

The appearance of these veins is remarkably uniform. The surface is marked by a heavy outcrop of gossan, which is particularly conspicuous on the knolls and ridges, where it is often found in great blocks scattered over a width of fifty or a hundred feet.* Beneath this gossan is found a mass of black cupriferous ore, which, like the gossan, has resulted from a decomposition of a mixture of the sulphurets of copper and iron. The depth at which this smut ore occurs varies, being greater on the hills than in the valleys. In the former locality, it is found 80 or 90 feet below the surface, in the latter it is reached at 25 or 30. It corresponds very closely as might be expected, with the water level. It is a mixture of the red oxide of copper with the sulphuret and some silicious matter, varying in its yield of pure copper

* J. P. Lesley, in his report on the Hiwassee mine, suggests that these veins may have been originally deposited as sedimentary rocks and subsequently altered by heat. Their parallelism is accounted for by the folded condition of the stratification, the upper curves having been removed by denudation.

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from 15 to 60 per cent., 20 per cent. being about the average. Below this is found the unaltered mineral of the vein, a very hard rock consisting of a pinkish iron pyrites mixed with quartz and containing some yellow copper ore.

The thickness of the veins containing these deposits is often enormous. At the Hiwassee mine, the body of black ore was said to be 45 feet wide, and at the Eureka, Mr. Staunton, the secretary, informs me there is a mass of solid ore 52 feet in width. At other points it thins out, and finally disappears. The thickness is equally variable. At some places it is accumulated in conical masses to the amount of several hundred tons. Whitney estimated the average width of the deposits at 10 feet and the thickness at 2.

One of the most remarkable features about these mines is the great economy with which they may be worked. Shafts can be sunk through the gossan without being timbered, and the ore can be taken out with picks and shovels, while the veins are so wide that several men can work abreast in the levels. The ridges too are so posited, as to afford great facilities for driving levels across the veins.

The permanent value of these mines will of course depend upon the character of the veins below the oxide, for, however rich and abundant that may be, it is evident that it must soon be worked out. The average of the rock is altogether too poor to admit of its being profitably worked, and unless the copper pyrites should be found to concentrate in rich bunches, these mines must be abandoned as soon as all the black ore is removed.

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Impressed with this truth, the miners have prosecuted certain openings with a view of determining this point. The Hiwassee mine, which has nearly if not quite exhausted its black ore, has cut several bunches of yellow ore in its lower levels, which have excited the hopes of its owners. According to the best information I have been able to obtain, however, I cannot regard this question as decisively settled.

The history of mining enterprise in this region, as given by Professor Safford, in his report to the Legislature, is briefly as follows. The first discovery of copper was made by a Mr. Lemmons, in 1843. He was washing for gold at the present site of the Hiwassee mine, and found red oxide of copper. Shortly after this, a company discovered the black oxide, but considering it worthless, they did not include it in a package of the minerals and rocks of the vicinity which they sent to New York for analysis. Receiving necessarily an unfavorable report, they suspended operations for the time being. In 1847, being informed by a German of the value of the black oxyd, they made a shipment of about 14 tons, averaging 25.3 per cent. About the same time a furnace was erected to make iron out of the gossan, but the metal produced was red short and the enterprise was abandoned. Still, certain facts were ascertained, such as the green flame of the furnace, and the cupreous hue of the iron after it had been heated and plunged into water. In 1849, Mr. John Caldwell came into the neighborhood, and mainly through his indefatigable energy, public attention was attracted to this region. In 1850, the Hiwassee and Cocheco companies

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were incorporated. The following year, the Tennessee Mining Company broke ground, and after that the tract was gradually taken up by the fourteen companies who now occupy it.

The *Hiwassee Mine* commenced regular operations in May, 1852, on a vein 45 feet wide, included in walls of mica slate. Other veins are spoken of as parallel. The main lode corresponds in strike and dip with the strata, having a direction of north 20 east and a dip of 80° to the southeast. The average depth of the black ore was estimated by Lesley at five feet, and its width at 30, the whole amount being calculated at 7200 tons. The mine has sent to market about 6000 tons and has exhausted its smut ore. Efforts are now making to strike the yellow sulphuret and the prospects are encouraging, several deposits of greater or less magnitude having been reported. As in all other mines, the gangue below the point of decomposition is a hard quartzose rock containing much iron pyrites and some yellow copper. The adit of this mine is 920 feet long, and serves as a draining gallery for the mine. The entire length of the shafts in September, 1856, is stated by Professor Safford at 641 feet, and the extent of the galleries at 2784 feet.

The capital stock is $240,000, divided into 60,000 shares.

The *Eureka Mine* is worked in a metalliferous belt 300 feet wide. This has been traced by an outcrop of gossan for 2250 feet, in the direction of the strike of the strata. The mine has been opened by a main shaft 105 feet deep, from which galleries have been driven across the belt. Several beds of ore have been cut, and

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from their direction they are expected to coalesce below. One of these presents a mass of ore 52 feet thick. There are now in view, according to the report, thousands of tons of ore.

The economy of freight is a matter of so much importance that the company has erected smelting furnaces at the mine. Wood is the fuel employed and the furnaces are on the reverberatory plan. The cost of smelting for a year is estimated at $21,272, the products of the furnaces for the same time being worth $67,742.

The capital stock of the company is $500,000 divided into 10,000 shares. The proceeds of the year ending March 21st, 1857, were 485 tons of ore averaging 23 per cent., 260 tons of regulus averaging 50 per cent. and 3766 pounds of copper.

The *Isabella Mine* has stopped on account of pecuniary difficulties. Its entire product has been estimated at 4000 tons averaging 16 per cent. Professor Safford states the production for September, 1855, at 120 tons containing 29 per cent. of copper.

The *Polk County Mine* is engaged in a suit about the title and has stopped in consequence. In September, 1855, according to the authority just quoted, it sent to market 108 tons of ore of 29½ per cent. Its entire production has been stated to be about 2500 tons of ore averaging 20 per cent.

The *Mary's Mine* has sent away about 1500 tons averaging 28 per cent. Its monthy product is about 40 tons.

The *London Mine* has very rich ores, averaging 45 per cent. Its monthly product is stated at 40 tons.

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The *Cocheco Mine* has been till recently in litigation. At present it promises well, the openings having exposed a large amount of marketable ore.

GEORGIA.—There are several localities in this state which are thought to promise well for copper but I have been able to obtain no definite information concerning them.

The *Canton Mine* is chiefly valuable for its silver-lead, but has produced also a remarkable ore of copper, called by Professor Shepard, Harrisite. It is a pseudomorph of galena and is very rich in copper, containing, according to Genth's analysis, nearly 78 per cent. of that metal. The vein, according to Professor Shepard's report, is a quartzy mica-slate, breaking into small blocks, and containing galena, copper and iron pyrites, and receiving a dropper vein carrying gray ore. The capital stock of the company is $960,000. They have already taken out large quantities of ore, chiefly silver-lead. They propose erecting a furnace at their mine, for the separation of the silver and lead.

COPPER ORES IN THE NEW RED SANDSTONE.

The new red sandstone is a belt of rocks which follows the flanks of the Appalachian chain, attaining its greatest development in Connecticut and New Jersey, where it is thirty miles wide. Throughout this range there are numerous irruptions of trap and in the vicinity of the junction of these two rocks the copper ores occur.

NEW ENGLAND.—In Massachusetts copper ores have been found, but have never been worked to any extent. In Connecticut, in the eastern end of the town of Gran-

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by, are the Simsbury copper mines which were worked in the early part of the last century. The company was chartered in 1709, and appears to have been the first incorporated mining company in the country. According to Professor Shepard, the ore occurs in beds, nodules and strings, in a fine-grained, yellowish gray sandstone. The principal ore is vitreous copper. A good deal of ore was taken out at different times, but about the middle of the last century, the mines were abandoned and lay idle for forty years, after which they were purchased by the State and used as a prison for sixty years. In 1830 they again passed into the hands of a company, were worked for a few years and finally abandoned.

New Jersey.—Quite a number of openings have been made in this State, and the carbonates, oxides and sulphurets of copper have been found in considerable quantities, but not at any point in regular veins. For the following history we depend chiefly upon Whitney's abstract, and upon Rogers' report on the geology of New Jersey.

From 1748 to 1750, several lumps of native copper, weighing in all over 200 pounds, were ploughed up in a field belonging to Philip French, near New Brunswick. A company was formed, and in 1751, a shaft was sunk on a spot "where a neighbor, passing in the dark, had observed a flame rising from the ground, nearly as large as the body of a man." After a time, a sheet of copper "somewhat thicker than gold-leaf," was found between walls of loose sandstone. Lumps also varying from 5 to 30 pounds in weight were taken out. After following the vein for 30 feet, the company abandoned their enter-

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prise on account of the difficulty of removing the water. Meanwhile they had stamped out and sent to England several tons of copper. It is said that sheets of copper "of the thickness of two pennies and three feet square," were taken from between the rock, within four feet of the surface.

The *Schuyler Mine*, near Belleville, in Essex county, on the left bank of the Passaic, seven miles from Jersey City, was discovered by Arent Schuyler, about 1719, The ore was abundant near the surface and easily mined. It was worked by the discoverer and his son, and before the year 1731, 1386 tons of ore had been taken out and sent to England. In 1761, the mine was leased to a company, which worked it for four years, and abandoned it after their engine house had been set on fire by a discharged workman. Several companies have spent a good deal of money on it since the Revolution, but it has never been profitably worked.

According to Professor Rogers' report, the principal body of the ore is embedded in a stratum of sandstone 20 or 30 feet thick, dipping about 12° from the horizon, rather by steps than regularly. It has been worked 212 feet below the surface and 150 feet horizontally from the shafts. The ores are principally sulphurets and carbonates of copper which are diffused through the indurated sandstone. There is no trap exposed on the surface anywhere in the immediate neighborhood.

At the Falls of Passaic, near Paterson, traces of copper have been found, and fruitless excavations have been made, in search of a regular vein. In the neighborhood of New Brunswick, "prior to the revolutionary war, an

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extensive and costly attempt was made to establish a mine, but without success." There are blue and green carbonates in the shale, and occasionally metallic copper is found in the shape of a thin plate injected into the body of the rock, which is hardened and changed from red to gray in the immediate vicinity of the metal.

At the *Franklin Mine* near Griggstown, in Somerset county, the ore is found in a shale altered by its proximity to trap. It is usually diffused, but sometimes occurs in narrow short strings, mixed with crystalline minerals. It has been worked to the depth of 100 feet and drained by a long adit. Much money has been expended here without any return.

The *Bridgewater Mine*, at the base of the trap ridge, north of Somerville, is another of these ruinous investments. As in all the others, the first openings were very promising. Out of the altered shale were taken quantities of red oxide of copper and native copper. Of the latter, two masses weighing 1900 pounds, are said to have been found in 1754. A smelting furnace was erected by some Germans about the middle of the last century, but soon abandoned. In 1824, the mine was again opened and worked, and as before, money was lost.

The *Flemington Mine* was the only one actually worked at the date of Professor Rogers' report, (1836.) He describes the ore as consisting of gray sulphuret and carbonate of copper, intimately blended and incorporated with semi-indurated and altered sandstone, parts of the mass having the appearance of a conglomerate of recemented fragments. The metalliferous belt, sometimes twenty or thirty feet wide, preserves a north and

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south direction for several hundred feet. The ores are mixed gray sulphurets and carbonates. They are of very good quality. I find, by reference to my record of analyses for 1849 and 1850, that commercial samples of lots sent to Baltimore varied from 28 to 50 per cent. An attempt was made at one time to smelt the ores on the spot, but resulted in loss. Some of the slag, containing 8 per cent. of copper, was sold in Baltimore. The mine was finally abandoned, the metallic deposit being too uncertain for profitable working. I visited the mine in 1855, but was not able to go down into the shafts, owing to the presence of water, and am consequently unable, from personal observations, to add anything to what has already been stated on the authority of Whitney and Rogers.

"It would seem as if these failures might have been sufficient to warn capitalists from wasting any more money in these mines. The State Geologist, in his report, remarks that there are no true veins in this formation, and warns against further expenditures, unless made with the greatest caution.

"Notwithstanding all this, New Jersey had, in 1846 and 1847, a little copper fever as well as Lake Superior. In 1847, there were six mining companies organized in this district, with 69,500 shares, and their market value exceeded $1,000,000. The Raritan mine, three miles southwest of New Brunswick, was purchased at a high price, and large expenditures were made under the advice of Dr. C. T. Jackson and J. H. Blake, Esq. The Passaic Mining company erected a steam engine and expended a large sum of money, near the old Schuyler mine. The Nechanic mine, near Flemington, which

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had been worked before the Revolution, was re-opened at a considerable expense. The Washington mine, near the old Bridgewater mine, at Somerville, was another of these unfortunate concerns, in which the future profits *per acre* were calculated to the fraction of a dollar.

"All these mines were abandoned, after heavy expenditures, with almost total loss of the whole amount invested; and it is to be hoped that no more money will be sunk in them."*

CUPRIFEROUS VEINS AT THE JUNCTION OF GNEISS AND NEW RED SANDSTONE.

In Montgomery and Chester counties, Pennsylvania, there is a metalliferous zone running east and west across the Schuylkill river, occupying a belt of country six or seven miles long, in the vicinity of Perkiomen and Pickering creeks, not far from the junction of the gneiss with the new red sandstone. Within this space are some ten or twelve lodes, some of which are confined entirely or chiefly to the gneiss, while others traverse the red shale. The former bear lead as their principal metal, while in the latter copper predominates. The gneiss is much decomposed to a very considerable depth, and is intersected by numerous dykes of granite, greenstone, trap and other igneous rocks, which sometimes cut the strata vertically and sometimes are parallel with the planes of the enclosing rock.

The *Perkiomen Consolidated Mining Company* was organized in 1851, by the consolidation of the Ecton and Perkiomen mines, both of which were on the same lode, their engine shafts being about 1800 feet apart. In

* Whitney. *Op. cit.*

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April, 1852, the report of the manager, C. M. Wheatley, states that the engine shaft in the Perkiomen mine was passing the 50 fathom level, and that the lode at that depth, was from four to nine feet wide, made up of quartz, gossan and sulphate of baryta, with green carbonate of copper and copper pyrites in place. It had decidedly improved from the 40 fathom level down. At the Ecton mine, the 54 fathom level was driving from the engine shaft west, in a lode varying from two to five feet in width, with good copper pyrites but not worth stoping. In May, 1853, the Perkiomen's shaft is reported to be 62 and the Ecton shaft 66 fathoms deep, but the lode poor in ore in both mines. From August, 1851 to April, 1852, 524 tons of ore, varying from 7 to 23 per cent. of copper, were sold by this company, for $30,573. In 1853, it is stated that the sales for the year were 142 tons of ore for $9,989.

Since September 1853, the mine has not been raising ores.

Ores have also been found in New Mexico and on the Gadsden purchase. The Arizona mine, in the latter tract, has sent to Baltimore and to Swansea very rich ores containing some fine crystallizations of the red oxide, but I have been unable to obtain satisfactory information concerning the mine.

Copper ores are also said to abound about the head waters of the Gila river, where several mines are reported to have been worked. The most celebrated is that of Santa Rita del Cobre, the ores of which are red oxyd imbedded in a red feldspathic rock. A Frenchman who worked it from 1828 to 1835, is said to have made half a million of dollars from it.

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CHAPTER V.

COPPER SMELTING.

THE object of smelting the ores of copper is, of course, to obtain the metal in a state sufficiently pure for the purposes of commerce. The degree of purity or fineness required depends upon the use to which the copper is to be put. For certain alloys it is not absolutely necessary that it should be perfectly malleable, while for tubes, wire, or sheets, it must be thoroughly refined.—The processes for obtaining it vary greatly in different countries, and depend entirely upon the nature of the ores and the character of the fuel which is employed. The simplest of these is that practiced upon the native copper of Lake Superior.

SMELTING LAKE COPPER.

For the purpose of obtaining pure malleable copper from the masses, stamp and barrel-work sent down from the mines of Lake Superior, it is only necessary to separate the earthy matter which still adheres to the metal, and then to deprive the copper of the oxygen it has absorbed while in the liquid state. The furnaces do not differ materially from those to be presently described, when we come to speak of the English method of smelting. They are reverberatories of an ordinary construction.

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Sometimes the whole process is conducted in a single furnace. In this case the ore is charged into the furnace, mixed with a flux adapted to the nature of the earthy matter under treatment. The heat is kept up till the whole is fused, when the copper, owing to its greater specific gravity, sinks, while the liquid earthy matter or slag floats upon its surface. This slag is now drawn off the face of the copper by means of rabbles, and the metallic bath is exposed. During the fusion, the copper has of course absorbed oxygen, which, if allowed to remain, would render the metal, to a great extent, fragile. The surface is, therefore, covered with charcoal, and rods of green wood are plunged into the metallic bath, in order to reduce the oxide. The refining being completed, the metal is laded out, and poured into moulds.

At other times, two furnaces are used, and in that case the metal is first obtained in the form of pigs, which are afterwards refined. The slags taken from these furnaces are very rich in copper, containing numerous shots and flakes of copper diffused through them. They are therefore worked over again with an additional quantity of flux, in order to obtain as much as possible of this retained metal. Still the slag is found to contain too much copper to be thrown away. In order to obtain this, the slags are passed through a small cupola furnace. The resulting slag may be considered clean, but there has been an unavoidable waste of copper, which has volatilized at the high heat of the cupola and passed out of the chimney.

The establishments at which the lake copper is worked, are at Detroit, Cleveland, and Pittsburgh.

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ENGLISH PROCESS OF COPPER SMELTING.

By far the largest amount of copper produced at any one locality for smelting, is obtained from the copper works of Swansea, in South Wales. Indeed the product of those great furnaces is estimated at more than one half of the entire world. The process there adopted is a tedious and intricate one, but appears, on the whole, the best adapted to a general smelting establishment. It is undoubtedly susceptible of improvement, as it has been recently estimated that not less than ten or twelve per cent. of the entire yield of copper in Great Britain and Ireland is lost in the smelting.

The average yield of the ores of British and Irish mines sold in Swansea, may be estimated at 6.7 per cent. The actual amount obtained from the furnaces does not amount to more than 6 per cent., so that 0.7 per cent. of the ore, or nearly 12 per cent. of the copper contained in it has disappeared. This statement, however, probably does not accurately represent the actual loss. Some of this has soaked into the bottoms, some has been carried into the culvert, where it is not beyond the reach of the smelter. Another portion, however, has gone away in the slag, and as it cannot be profitably extracted, it is irrecoverably lost.

To meet this loss, the smelters have adopted a series of rules, which transfer it from their shoulders to those of the miners. In the first place, the smelter's ton consists of 21 hundred weights, or 2352 pounds, so that five per cent. is gained here. Again, the ore is all bought by the dry essay. This, as has already been said, is never accurate, the loss being greater in the crucible

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than in the furnaces. This difference between the assay-room and the works, increases in an inverse proportion to the richness of the ore. Thus, in an ore ranging from three to six per cent., the crucible loses at least fifteen per cent. of the copper more than the furnaces, while in one containing twenty-five per cent., the difference would not be more than five per cent. Besides these, there are minor charges put upon the ore. Much dissatifaction has for some time existed on the part of the miners at these arrangements, but experience has long since proved that they would lose far more if they undertook to smelt for themselves. Independently of the superior advantages which the smelters at Swansea enjoy, in the proximity of coal, and the facilities for transportation, they can work cheaper than the miners, because there is always a decided loss attending the attempt to work one class of ores alone.

The rationale of the process adopted at Swansea will be better understood after an acquaintance with the character of the ores smelted there. These are divided into five classes:

First Class.—These consist almost entirely of copper pyrites, containing a large proportion of iron in the state of sulphuret, and mixed with much *mundick* or iron pyrites. They contain little or no carbonate or oxide of copper. The earthy and silicious ingredients are in large proportion, so that the amount of copper ranges from three to sixteen per cent.

Second Class.—Resembles the first, with the difference that they are richer, containing from fifteen to twenty-five per cent. of copper.

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Third Class.—Copper pyrites containing but little iron pyrites or other substance likely to impoverish the metal produced, and having a large proportion of oxidized ores of copper.

Fourth Class.—The basis of these ores is usually quartz. They contain from twenty to thirty per cent. of copper in the form of oxide and carbonate, mixed with some sulphuret.

Fifth Class.—Rich ores from Chili or South Australia, containing often eighty per cent. of copper, in the form usually of carbonate or red oxide. The gangues are commonly silicious.

It is evident that the object to be attained is the liberation of the copper, not only from the earthy matters in which its ores are imbedded, but also from the sulphur, oxygen and iron with which it is chemically combined. These results are arrived at by a series of calcinations and smeltings, which vary with the ore under treatment. M. Le Play has classified these various processes under ten heads, and we shall follow his order in describing them.

I. Calcination of the ores of the first and second class to expel sulphur.

II. Melting the calcined with raw or unburnt ore, to separate the earthy matters and to obtain a matt or *coarse metal.*

III. Calcination of the coarse metal still further to expel sulphur.

IV. Fusion of the calcined metal with rich ores of the fourth class, to get rid of iron and obtain white metal.

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V. Melting for *blue metal*, or fusion of the calcined coarse metal with roasted ore, moderately rich in copper.

VI. Re-melting of rich slags to recover the copper contained in them.

VII. Roasting for white metal, or production of white metal of extra quality. This operation sometimes includes the roasting of the *blue metal* obtained in process V.

VIII. Roasting for *regulus*.

IX. Preparation of crude copper, by roasting and melting white metal, regulus, &c.

X. Refining and production of tough malleable copper.

The furnaces in which these operations are performed are all of the reverberatory form, but differ in their dimensions and the slope of the roof. In well-conducted establishments, they are all connected with an underground culvert in which volatilized copper is arrested and recovered.

The *calciner*, in which the first operation is more spacious than the others. The hearth, or laboratory of the furnace, is elliptical in form, truncated at the extremities of its long axis, and having, between the openings through which the charge is removed, angular projections towards the centre of the bed. It is sixteen feet long, and thirteen and a half wide. It is formed of fire-bricks set on edge, and firmly bedded in refractory fire clay. Each of its sides is provided with two working doors, through which the various operations of stirring and raking down the ore are performed. Immediately within each of these doors, is an opening through

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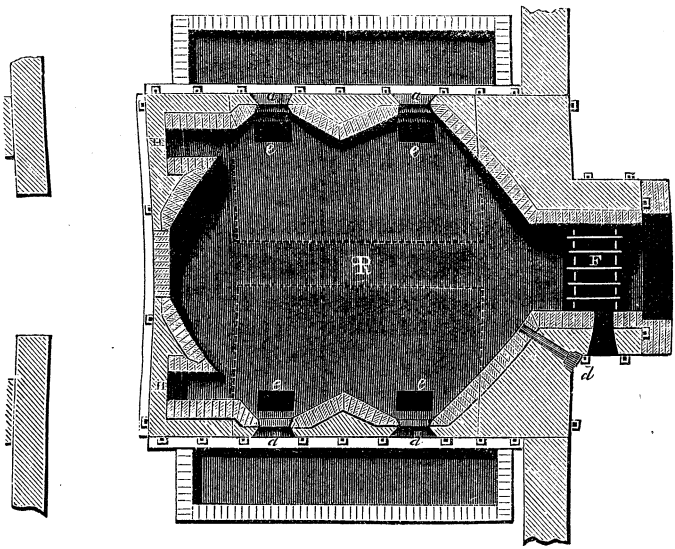
FIG. 9.



PLAN OF CALCINING FURNACE.

R, Sole of furnace. F, Fireplace. *a a*, Side or working doors. *e e e e*, Openings communicating with the vault. *d*, Special air-hole, which can be opened or closed at pleasure. H H, Flues.

which the calcined charge is raked down into the arched chambers beneath. While the calcination is going on, these are kept closed by iron plates which are removed at the close of the operation, to admit of the removal of the roasted ores. The arch, which has a mean height of two feet above the sole, descends rapidly from the fire-place to the flue-holes, at the other end of the long axis, through which the gases escape into the chimney. A current of cold air is admitted by an opening near the fire-place, which can be closed at pleasure. In some

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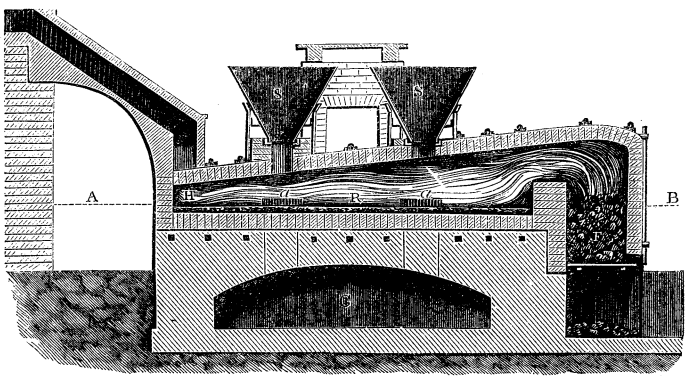
forms of the furnace, a channel is made in the fire-bridge, through which passes a current of air having the advantage of being heated, and consequently more active.

FIG. 10.



CALCINING FURNACE. SECTION.

A B, Level of sole. C, Vault into which the calcined ore is raked. H, Flue. R, Sole of furnace. *a a*, Working doors. S S, Hoppers.

The arch of the furnace supports two large hoppers of sheet iron, provided with sliding doors at the bottom. Into these the ore is placed, and allowed to drop into the furnace on the removal of the slides. Outside, the furnace is bound together by strong iron bands, arranged both perpendicularly and horizontally.

The coal used in the Swansea works is anthracite, the combustion of which presents many difficulties to be overcome by the smelter. It ignites slowly and imperfectly, and on being heated flies into powder, which either falls through the bars, or accumulates and chokes

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the draught. Besides, it produces a fusible ash, which, at a high temperature, runs into a glassy slag, that not only chokes the draught, but rapidly corrodes the bars of the grate.

To obviate these difficulties, the smelter has recourse to very simple methods. He places his grate-bars wide apart, and throws pieces of scoria loosely upon them till he has formed a layer about a foot thick. Upon these the fire is made, and the ashes accumulate. They all fuse together to a spongy silicious mass, everywhere traversed by a great number of apertures. As this matter accumulates, the fireman, from time to time, detaches the lower portion and allows it to fall into the hearth. Thus he has a grate formed of slag, containing interstices too small to permit the fragments to fall through, and yet sufficient for a draught. The gases arising from this combustion consist chiefly of carbonic oxide, which passes over the fire-bridge into the body of the furnace. Here it meets the stream of air introduced through the openings already mentioned, and others which are left in the iron-plates closing the lateral openings. Thus the whole cavity of the furnace is always filled with flame, caused by the carbonic oxide burning as it comes in contact with the atmosphere. The minerals spread over the sole, are, therefore, exposed to a current of air, above which is a parallel sheet of carbonic oxide, burning on its under surface where it comes in contact with the oxidizing stratum, and so affording sufficient heat to conduct the entire operation.

The charge, which consists of three or three and a half tons, is introduced without any intermission in the action of the furnace, by simply withdrawing the slides

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at the bottom of the hoppers. As soon as it has been let down, it is spread evenly over the furnace bottom by means of long iron rakes introduced through the working doors, which are then immediately closed. The fire is then replenished with the proper amount of coal, the cinders loosened, and the heat gradually raised. The object of this process is to get rid of a certain amount of sulphur; but, in order to accomplish this, great care is necessary. If the heat be pushed too rapidly at first the ore will agglutinate, thus shielding a portion of it from the influence of the air, and impairing the result, besides obstructing the walls and sole of the furnace by collections of fused sulphuret. After six or eight hours, the heat may be raised, as then much of the sulphur has been expelled, and the disposition to agglutinate is less.

At first, watery vapor passes off, and then sulphurous acid. To facilitate the action by exposing fresh surfaces to the action of the oxidizing agents, the charge is stirred every two hours, by a long iron tool called a rabble, till no more volatile products pass off, or until the peculiar stage of oxidation demanded by the condition of the ore, and exigencies of the other furnaces is attained. Towards the close of the operation, the heat is pushed, and the furnace raised to its highest temperature. The iron-plates covering the openings behind the doors are then removed, and the calcined ore raked down into the chambers below. This is a trying operation to the workman, as the unpleasant effects of the heat are increased by the fumes of sulphurous and sulphuric, and often of arsenious acid, which arise from this glowing mass. These are caused by the presentation of a greater surface to the action of fresh air, which evolves still

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more gas than was expelled in the furnace. Immediately after the removal of one charge, another is introduced. The time occupied by this operation is usually twelve hours, though it sometimes reaches twenty-four.

Little or no loss in weight is sustained in calcination, as the sulphur expelled is substituted by oxygen absorbed. M. Le Play, who carefully examined these operations, has given the following tables of the ore before and after calcination, which show the chemical changes it has undergone.

BEFORE CALCINATION.

Oxide of copper, isolated or combined,	0.374
Copper pyrites,	22.710
Iron pyrites, bisulphide of iron,	22.442
Various sulphides,	1.001
Oxide of iron,	0.608
Other oxides,	0.269
Quartz and silica,	34.428
Earthy bases,	1.871
Water and carbonic acid in combination,	0.491
Oxygen consumed,	15.806
	100.000

AFTER CALCINATION.

Oxide of copper,	5.401
Copper pyrites,	11.228
Bisulphide of iron,	11.226
Other sulphides,	.600
Ferric oxide,	11.718
Other oxides,	.608
Sulphuric acid in combination,	1.108
Quartz and silica,	34.408
Earthy bases,	1.874
Gaseous products, Sulphurous acid,	21.338
Gaseous products, Water and carbonic acid,	0.491
	100.000

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In these tables, no account is taken of the arsenical products which are scarcely ever absent. The matters escaping from a calcining furnace may be said to consist of

Vapor of water,

Sulphurous and sulphuric acids,

Arsenious acid, and arsenical vapors,

Fluoride of silicium, and other volatile compounds of fluorine,

Solid matter, mechanically conveyed by the draught into the flue,

Carbonic acid, &c.

The water comes from the oxidation of the hydrogen of the coal, as well as from the moisture contained in the ore. Coming in contact with the sulphurous acid, it gives rise to sulphuric acid. The fluoride of silicium results from the action of the silicious gangue upon the fluor spar (fluoride of calcium) contained in the ore. The rest of the volatile products need no particular explanation.

All the vapors pass off into the atmosphere, and from their enormous quantity, exert the most unfavorable influence upon vegetation. Not a blade of grass can grow for a considerable distance around Swansea, in the direction of the prevailing winds, so that the smelters are obliged to incur the expense of buying up large tracts which they do not want and cannot use. The curse of absolute sterility rests upon the environs of the furnaces, and this will surprise no one who has ascertained, by a simple calculation, that the amount of sulphurous and sulphuric acids given off from the numerous chimneys of Swansea, cannot be less than ninety thou-

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sand or one hundred thousand tons. The loss has not been confined to the agriculture of the district alone; the smelters have also suffered. The sulphur, volatilized, is worth £120,000 a year, and if estimated as common commercial sulphuric acid, to which condition it could be easily reduced, it would afford an annual revenue of £450,000.

Some attempts have been made to get rid of the poisonous fumes. At first it was thought that, by erecting very tall chimneys, these vapors would be mingled with a large bulk of air, and so neutralized by the ammonia, as to be rendered comparatively inert. Again, it was attempted to build vitriol chambers in connection with the shaft. Another plan was to conduct the volatile matters through long galleries or troughs holding water, and covered by perforated slabs of stone placed horizontally, over which a stream of water was kept constantly flowing. In these troughs, they meet the percolating water which absorbs much of the sulphuric acid. The difficulty, however, was that the presence of so much liquid interfered with the draught, so that the measure was abandoned.

Second Operation. The ore, being cooled, is wheeled in barrows to the next furnace, in which the first smelting is performed. The object is to separate as much as possible of the iron and all of the earthy matters. The temperature employed is higher, and the charge much less, than in the preceding operation. The iron enters into combination with the silica, forming a fusible slag, and though there is usually enough silica to combine with the iron, it is customary to add a slag rich in cop-

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per, from one of the other furnaces, in order to effect a more thorough combination. As the slags from this process are usually rejected, it is important to have them as clean as possible. There is always, however, a portion of it which contains a little copper mechanically mixed with the scoriæ, which is sent back to the furnace to be worked over. The residue, which is called "clean slag," is thrown away, or employed to make roads, to raise the grade of the yards, to lay the foundations of other furnaces, &c. In spite of all the uses which have been found for it, however, it becomes quite a serious matter at Swansea to determine how it shall be disposed of. Beginning near the furnaces, and gradually going further and further, the smelters have surrounded their works with hills of refuse. Of late, it has been the practice of some of the establishments to form the rejected slag into tiles, slabs, and bricks, suitable for building.

There is always a little loss of metal in this slag, which is generally estimated at from four to five-tenths of one per cent. of the entire metal contained in the ore. It can, however, with care be reduced to two or three-tenths, though this is by no means common.

The furnace in which this operation is performed, is not more than one-third the size of the calciner. In most furnaces it is charged through the top, and consequently needs no side-door; but in some, it is provided with one side-door, through which the charge is introduced. At the opposite side of the furnace is an opening, called the tap-hole, through which the molten metal is allowed to flow out. The bottom is made of a refractory sand, which is agglutinated by heat, before the

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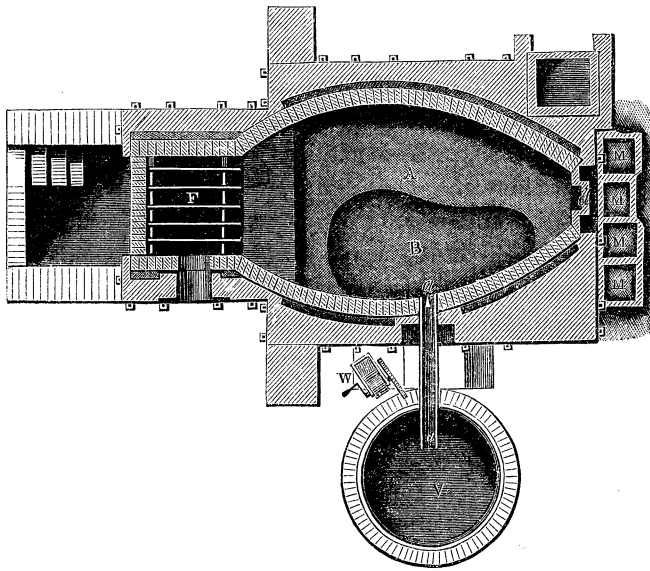
FIG. 11.



SMELTING FURNACE PLAN.

A Sole of furnace. B, Depression for the accumulation of metal. F, Fire-place. MMMM, Sand moulds for slag. V, Water tank. W, Winch for raising from furnace.

a a Outlet for melted metal. *d* Working door for draining off slag.

charge is introduced. It is depressed towards the tap-hole, to allow the molten metal to flow out readily, and so worked as to form a sort of basin immediately within that opening. In front of the furnace is a door, through which the scoriæ are raked out, the ore stirred, and the various repairs of the furnace bottom accomplished. Immediately below this door, outside of the furnace, are sand-moulds to receive the fluid slag, which is withdrawn from the surface of the metal. Near the tap-hole is usually a tank of water, with an iron pot on the bot-

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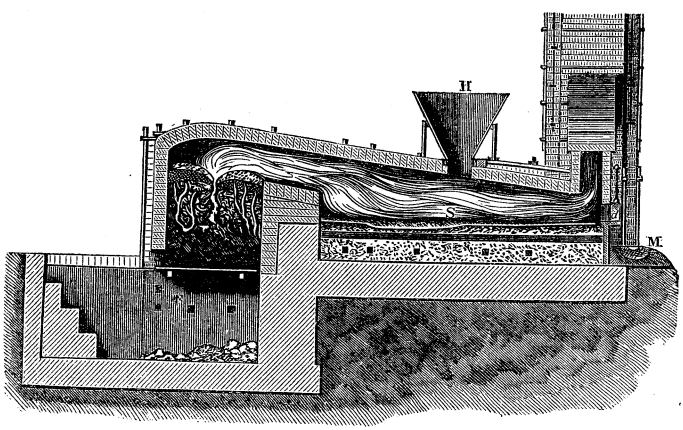
tom, which may be lifted out by a crane. In this, the metal tapped out from the furnace, becomes granulated. The fire-place is larger in proportion to the size of the furnace than in the calciner. Its dimensions are about four feet by three and a half, while that of the bed of the furnace are only about eleven by seven. The fire is made as usual, but at Swansea about one-third of bituminous coal is added to the anthracite for the purpose of obtaining a hotter fire than the calciner can furnish, the greater heat being needed for the fusion of the substances.

FIG. 12.



SMELTING FURNACE SECTION.

H. Hopper for charging. M, The other letters have the same reference as in the preceding figure.

The charge usually consists of seventeen or eighteen hundred weight of calcined and two or three hundred weight of crude ore of the third class. To these are

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added three and a half hundred weight of slag containing copper, and obtained from operations IV., V., and VII. These subserve the double purpose of rendering the slag more fusible, and of giving up to the metal the copper they contain. The ore and the finer portion of the flux are introduced through the hopper, and the coarser portions of the latter are thrown in at the door. This is quickly spread upon the bed of the furnace, and the larger pieces of slag are then thrown in. The charge having been introduced, the door is closed and luted, and the tap-hole blocked up with sand and scoriæ. The fire is then pushed, and the charge remains undisturbed for about three hours and a half, except for the necessary examination of the process. Fresh fuel is thrown on at the end of an hour and a quarter, or thereabouts. This furnace consumes about thirty-four and a half hundred weight of coal in the twelve hours.

The first effect of the heat becomes manifest in about half an hour after the spreading of the ore on the hearth of the furnace. The slag then begins to melt and form little pools or channels full of liquids. Soon after, the fluid mattter begins to extend over the hearth, in consequence of the formation of a fusible silicate by the iron and silicic acid present in the ores and slags. As the quantity of liquid matter increases, it is agitated by the evolution of sulphurous acid gas, formed at the expense of the sulphuret of iron, which becomes oxidized, and combines with the silica. Fluor spar greatly assists these actions, its fluorine entering into combination with the silica, and forming a volatile compound which carries off arsenic. At the end of the three hours and a half, the

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charge is nearly melted. The furnace man now opens the door, and by means of a long rabble, stirs it, bringing the unmelted portions more directly in contact with the fused mass, and causing it to fuse. The heat is now increased, and kept high till the fusion is completed. The molten bath is now divisible into two layers, the upper containing the earthy, and the lower the metallic contents of the ore. The former of these is now removed through the front door by a process of rabbling. In some instances, a new charge is now thrown in on top of the bath, to increase the metallic yield of the furnace, but usually the "coarse metal," as it is called, is tapped out, and a fresh charge introduced afterwards.

The separation of the slag from the metal is never perfect. A little copper is always found in the lower layer of liquid. Most of this subsides to the bottom of the central pig of slag, which is kept liquid by the continual addition of fresh molten matter from the furnace. What is not arrested by this plate slag, passes over to those on either side of it. The quantity of metal contained in these slags, varies with many circumstances. Thus, if the matt be very poor, and the slag of nearly the same degree of fluidity with the metallic bath on which it rests, there will be more metal mechanically mixed with it than if the matt were heavier, or the difference in the fluidity of these two superimposed baths greater. The cleanliness of a slag depends upon a proper adjustment of all these particulars, and requires no little skill and experience for its accomplishment.

The slag, having cooled sufficiently, is wheeled out to the heap, where it is broken up and examined. Those

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fragments which contain metal, are sent back for re-smelting with the next charge. It is no easy matter to attain the exact composition of a charge to produce the best effect. The most important point is to make such a fusible mixture that the matt may subside by reason of its greater specific gravity, and separate exactly from the slag. This is greatly assisted by the oxide of iron in the scoriæ of the fourth operation, which are, as we have already said, added to the charge. Much, also, depends upon the admixture of earthy matters in the ores. The best results are obtained when these are so proportioned as to form a highly crystalline slag. In practice, it is customary to make several trials with different combinations of the ores in the yard, until such a mixture is hit upon. After that, nothing is required but to follow the routine thus established. When the variety of ores is large, the simplest plan is to mix the poor and rich ores in such proportions as to obtain the average per centage of the matt, when the various earths in combination with the different ores flux one another, and give the desired result. It is, however, evidently not always possible to do this. In cases of difficulty, the usual practice is to make a full quantitative analysis of the ores, and to construct a proper mixture by the light thus afforded. It may happen that this reveals the fact that the ores alone will not produce a fusible mixture. In this case, fluor spar or limestone is added; but it is desirable to avoid this, if possible, as, if too great a quantity of slag be made, a corresponding loss of copper will be sustained by the mechanical retention of minute particles of metal.

The man who superintends this operation is called

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the *roaster-man*, and much depends upon his skill and knowledge of the working of the furnace. He determines the heat by inspecting the interior of the furnace, through a hole in the tile which closes the door, to ascertain if it has reached the proper degree of incandescence. If it be not hot enough, the fire is examined to determine whether the fuel be excessive or insufficient, and whether the draught be strong enough, and the defect, when ascertained, is immediately remedied. It is important to regulate the quantity of air passing through the furnace. If this be too great—that is, more than sufficient for the combustion—it shortens the flame and diminishes the heat.

Four hours are required to work off each charge, so that this about balances the calciner, which, though much larger, requires much longer time to do its work. The heat must be kept up during these four hours, in order to keep the contents of the furnace in perfect fusion. If this is not done, the ore may adhere to the bottom. At the end of the heat, the slag is skimmed off, as already described, and the furnace tapped. The entire amount of slag is not, however, removed, as, in that event, the matt would be covered with a layer of oxide of copper, which would diminish its fluidity, and render it difficult to flow out from the furnace. A little slag is also left in the furnace, to obviate the corrosive action of the ore upon the hearth. The matt is usually allowed to flow into the tank of water already described, where it is granulated. As soon as it is cooled sufficiently, it is raised out of the tank, and removed to the storehouse, to await the next operation. When it has

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all flowed out, or sometimes while it is still running from the furnace, a fresh charge is introduced, which is worked in precisely the same way.

Two men at a time manage this furnace, which works day and night throughout the week. Each pair of men has charge of it during twelve hours. On Saturday night, the furnace is put on what is called "dead fire," for Sunday—that is, it is merely kept hot, without being charged with fresh ore. On Monday morning, or Sunday night, according to the regulations of the works, it is again charged and kept at work for another week. The night work is taken alternately by the men, who are paid by the ton, and are not allowed anything for working over their foul slag.

The chemistry of these operations is very simple. The principal change which takes place is the formation of a silicate of iron and the expulsion of sulphur. There is usually enough silica in the ores to take up as much of the iron as is desired. When this is not the case, quartz sand is added. Iron has a strong tendency to unite with silicic acid at high temperatures, especially when the oxide is brought into intimate admixture with silica by means of a fusible flux. Silicate of iron and fluor spar combined, answer this purpose admirably well. The oxygen gas of the air passing over the fused materials burns off the sulphur, and converts the iron into an oxide which unites with the silicic acid. The evolution of gases causes a commotion which greatly facilitates the operation. Fluor spar acts by parting with its fluorine to silica which should be in excess, forming volatile flouride of silicium, which bubbles up through the mass. It mixes the materials well, and renders the slag fluid by the for-

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mation of another silicate, that of lime, thus preventing the stiffening of the slags by an excess of silica. It gets rid of this excess by removing a portion of it directly, in a volatile gas, and by forming a fusible silicate with another portion. Limestone acts only in the latter way. It is evident that both are useful chiefly where there is too much silica for the iron.

The resulting matt is a mixture of sulphuret and a little oxide of copper with sulphuret of iron and small quantities of other metals. The earthy matters, some of the sulphur, and much of the iron have been separated in the slag or the volatile products.

Third Operation.—The granulated matt is charged into a furnace precisely similar to that used for calcining the ore. Care is taken to prevent the fusion of the matt, which would prevent the proper action of the air. For this reason, the heat is kept down at first and gradually pushed towards the close of the operation, which lasts about twenty-four hours. During this time, the matt is rabbled every two hours in order to change the surfaces and expose the sulphurets freely to the action of the atmosphere. At the close of the operation, the furnace should have attained a bright red heat. To effect this roasting, thirty-three hundred weight of coal are used.

The metal has now changed from a dark, reddish gray to a brownish black, and has become more friable. The chemical alteration consists in the further oxidation of the metals and the expulsion of still more sulphur. The loss of weight is not considerable, because oxygen has, to a great extent, taken the place of sulphur. Thus, 1000 parts of crude metal will furnish 974 of calcined metal, and 270 of sulphurous and sulphuric acids.

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Fourth Operation.—The object of this operation, which is performed upon the calcined coarse metal, is to separate, as far as possible, the iron from the sulphuret of copper. It is usually, however, not confined to this simple and direct melting, but advantage is taken of it to work down other ores of the fourth class, which contain little sulphide of iron, and are rich in copper in the state of sulphide and oxide, as well as the rich scoriæ from the upper furnaces. It requires no little skill so to blend the heterogeneous materials of this charge as to produce a satisfactory result. There are smelted in this furnace, not only the calcined metals, rich ores, and scoriæ, but also the various sandy and calcareous matters from the walls and soles of furnaces which may have become impregnated with copper. The table will give some idea of their usual proportions:

Calcined coarse metal from the third operation, .	559
Crude ores, ...	243
Copper scales from the rolling mills, &c., . .	7
Scoria from the ninth operation, . . .	60
Scoria from the tenth operation, . . .	24
Furnace waste (cobbing) from the second to the tenth operations, ...	60
Earthy matters, sand impregnated with copper, .	41
Earthy matters, bricks impregnated with copper,	6
	1000

It will be understood, of course, that this table is intended to give merely an approximate idea of these proportions, as it is very evident that the working of substances

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so very various in their composition and metallic contents, cannot be carried on by any fixed formula, but must vary with their changing constitution. The criterion for the workman is the practical result of the first charge. He may succeed in getting a fine sulphuret of copper with a comparatively clean slag at the first trial, but he may, on the other hand, produce a metal containing a large proportion of sulphuret of iron, and a slag in which there is a good deal of oxide of copper.—It is generally believed that the best results are attained where there remains in the matt a little iron, say from four to ten per cent., and from three to five per cent. of copper pass off in the slag. This does not interfere with the success of the work, as these slags are all smelted over again in the lower furnaces, where the copper is recovered. It is, however, necessary to guard against an excess of this oxide of copper in the slag, as it will react upon the sulphuret and produce metallic copper, which is not desirable at this stage of the process, since it would deteriorate the product.

The furnace in which these operations are performed, resembles that devoted to the second fusion, except that there is no cavity in the hearth, but a gentle slope towards the side at which the fused material is run out. The fire is managed in the same way, but the heat is greater on account of the greater consumption of fuel. The materials are introduced either through the hopper or the side-door, the larger portions, especially the scoriæ being thrown through the door. They are then spread evenly over the sole of the furnace. The charge weighs about thirty-two hundred weight.

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The doors are now closed and luted, and the fires regulated so as to calcine the surface. In about an hour the mass begins to soften and evolve a good deal of gas, arising from double decomposition, and in about three hours after charging, the fusion is nearly completed, the furnace presenting the appearance of a bath upon which the unmelted matter floats. In about four hours from the time of charging, the matter adhering to the walls of the furnace is raked down and the whole mass well rabbled. In a short time, the fire being pushed, the contents of the furnace are in a state of tranquil fusion. The heat is still gradually raised until the metal is thought to be sufficiently purified, which generally happens in about six hours from the time of charging. The scoriæ are raked off by the front door, and the fluid matt tapped out at the side, either into sand moulds where it is cast into pigs, or into a cistern to be granulated.

The results of this operation are a *white metal*, which contains but little foreign matter, being a nearly pure sulphuret of copper, and slags or scoriæ which are brittle and crystalline, and contain, as already stated, some oxide of copper. In Swansea, a special operation is resorted to for the purpose of recovering the copper contained in these scoriæ. They are broken to pieces and divided in two lots, of which the poorer is worked in the first fusion, while the richer, being mixed with pulverized coal, are melted to obtain their metal, which is white and brittle. The scoriæ resulting from this special melting are partly thrown away and partly employed in the first fusion.

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The products of the fourth operation have been stated in the following manner:

White metal, ...	402
Poor slag, ...	261
Rich slag, ...	281
Furnace waste, . . .	9
Sulphurous acid, . . .	43
Water and Carbonic acid,	4
	1000

The white metal is grayish white or blueish, with a strong metallic lustre, containing many small cavities which are often lined with copper. Its composition is:

Copper, . . .	73.
Iron, ...	6.5
Sulphur, . . .	20.5
	100.0

Sometimes there is only fifty per cent. of copper in it, but this is below the standard.

Fifth Operation.—The usual routine hitherto followed in the several processes, in dealing with the ore, is interrupted here, and the product of the fourth fusion is not used, but only substances of a different nature and class, hence, to tabulate the course of procedure in the way in which the above order indicates, would appear contradictory and confusing; but it is customary in the copper foundries of Swansea, to adopt this plan of working fresh materials with the slag and various other matters containing copper, and to bring the valuable matter

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in them into a fit state to undergo the same operation as the product resulting from the last fusion, an operation to be described under the ninth stage. There is another purpose in view and this is the production of a better quality of copper. Rich foreign ores and matt which are imported into Swansea, if mixed with the ordinary productions of Cornwall, would give a metal only of medium quality, having some good but many bad qualities. It is the practice, in these cases, to work only the copper ores which are free from the more difficultly eradicated impurities, and for this purpose the intermediate fifth, sixth, seventh and eighth operations are added to remove the copper from the ore and the slags formed in the state of white or blue metal. Three of these, the fifth, seventh and eighth, are grouped together under the designation of the *extra process*, to distinguish them from the ordinary course, which would link the fourth and ninth operations together. Both are, however, intimately connected in more ways than one; for instance, the material used is identical with the product of the second fusion or coarse metal; this union is brought closer by the use of the richer slags from the last operation.

When they have undergone another fusion, the resulting matt of white metal is submitted to the seventh and eighth fusions, as well as that derived from the extra product of the fusion under consideration, and the whole is treated in the ninth operation indiscriminately. Indeed these several stages for enriching the matt, although they bring about reactions more efficacious towards removing the substances which might deteriorate the copper than the fusion in the fourth one, still are nearly

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identical with the latter and with the ninth operation yet to be described. This is especially the case in regard to the fifth fusion, which is only a modification of the preceding one, and the roasting in number seven and eight are merely repetitions of the ninth method.

The material employed here is, as already stated, chiefly composed of calcined matt from the purer variety of ores; but, in general, a quantity of the ordinary substance resulting from the second calcination, is taken and incorporated with other materials, in the annexed ratio:—

Calcined coarse metal from third operation,	0.722
Calcined ore of the second or third class, .	0.185
Earthy matter—silicious, . . .	0.084
" " bricks, ...	0.009
	1.000

The furnace in which the process is conducted, is identical in form with that used for the last fusion; if the composition of fuel is in this as in the foregoing, composed of anthracite and caking coal. The time occupied in working the charge is about six to seven hours, making twenty-two charges per week. Like the substances used in the fourth operation, these undergo a gradual fusion, which, toward the close, becomes urged by a very high heat. Very little change is exerted till the matter becomes liquefied, when the oxide of copper reacts upon the sulphides of iron, giving rise to a sulphide of copper and an oxide of iron, which enters into combination with the silicious matter, and generates a

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very fusible scoria. Sulphurous and sulphuric acids are likewise liberated: but a portion of the sulphur is substituted for the oxygen derived from the oxide of copper, thus converting the whole of the latter into a sulphide. This constitutes the refining process which is chiefly intended in this operation, namely, the removal of the iron and excess of sulphur, leaving the copper combined with the least quantity of the latter element. The weight of the charge is two tons; and the results after the fusion may be expressed as in the annexed table:—

Blue metal for the seventh operation, .	0.495
Scoria for the second operation, . .	0.434
Furnace waste for the fourth operation, .	0.008
Sulphurous acid, ...	0.056
Oxygen, ...	0.007
	1.000

After the charge is worked off, the matter closing the tap-hole is completely removed, and the cupreous fluid which is called blue metal, permitted to flow out into moulds. The slag is then permitted to run out of the same orifice.

Sixth Operation.—In this stage, the slags resulting from the preceding and the two succeeding fusions, and which are rich in oxide of copper, as well as some rich sulphide of copper from certain ores, which, however, are free from injurious substances, are treated. The furnace in this case is slightly modified to suit the material which is being operated upon. No hopper is appended, in consequence of the substance being in too

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large pieces to conveniently pass through; but a charging door is formed in one side; and when the lumps of scoria are injected, very little exertion is required to spread them evenly over the sole of the furnace. During the succeeding treatment, this door is kept closed and luted at the sides, so that no air can enter. When the matt is ready, it is drawn off, as usual, through an orifice for the purpose, made at the extremity of the transverse diameter of the hearth, opposite the side in which the charging takes place. The medium of heat is the same in this as in the other furnaces, and the time occupied in working extends to about five hours and a half. As the quantity of oxide of copper in the scoria employed cannot be wholly converted into sulphide of copper by the action of the sulphur combined with the iron in the ore added, it is reduced to the metallic state, and afterwards purified in the succeeding treatments. This is brought about by adding to the substance slack, or ground coal or charcoal; the results of this reaction are carbonic acid and metallic copper, which, owing to its greater gravity, penetrates the scoria and matt, and forms a layer of impure black copper, or *bottoms*, on the hearth. In this behaviour the reduced metal effects an important part in purifying the matt of sulphide of copper; for it reduces and precipitates with it certain portions of tin and arsenic which are present, the removal of which would otherwise be difficult, and the presence of which would operate deleteriously upon the quality of the metal. The nickel and cobalt which sometimes exist in cupreous minerals are in like manner decomposed and carried down in the black copper, their sulphur being

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transferred to a portion of the oxide of copper in the slag. A product of great excellence is the result of these various depurating reactions, and is called by way of distinction, *best selected*, when it is reduced, and while in the state of matt, *hard metal.*

In the charge for this furnace, which amounts generally to two tons, the several substances are taken in the proportion of the annexed table, or thereabouts, viz:

Rich slag from the fourth operation, .	0.671
" " seventh " . .	0.095
" " eighth " . .	0.053
Copper pyrites, ...	0.079
Sweeping of the foundries from the eighth, ninth, and tenth operations, . . .	0.055
Carbon employed as re-agent, . . .	0.001
Earthy matters—sand, ...	0.036
" " brick, ...	0.010
	1.000

Details of working similar to those pursued in the fourth fusion, only that the hearth of the furnace is in this instance more liable to corrosion, because sulphurous products are in much less abundance, and the scoria and iron react upon it, abstracting the silica. Such is the case, especially in the parts adjoining the walls; but as a preventive, the slag is piled round in these parts, and as soon as the matter becomes molten, the quartz, which forms a considerable part of the ore added, supplies siliceous matter to the iron, and the hearth is preserved.

At the close of the process, the fused matter is

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three layers; the upper is constituted of the scoria, the middle of fused matt, and the lower of black copper: these are drawn off as usual. These products may be tabulated as under—

White metal for the eighth operation,	0.057
Red metal " " "	0.016
Tin alloy,	0.005
Copper bases for operation,	0.008
Slag to be rejected,	0.901
Refuse of furnace for fourth operation,	0.006
Carbonic acid,	0.003
Water and carbonic acid from ore,	0.001
	1.000

Seventh Operation.—Blue metal is here converted into white metal, by the agency of the air; and the chief or entire part of the remaining iron is removed, by forming a fusible silicate towards the close of the calcination. The furnace which is requisite for this double purpose is constructed like that mentioned under the last stage, with charging doors at the side and end, opposite the fire, and a tap-hole at the other side at the end of the middle transverse diameter. In addition to these air is admitted by openings near or through the bridge of the hearth, as already described in reference to operations for roasting. Crude blue metal constitutes the charge; but it carries with it a certain quantity of sand from the moulds wherein it was cast, and during the working near a ton of the materials of the furnace are disintegrated and carried off in combination, partly

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with the iron of the scoria, so that the components of the charge may be represented in the relative proportion expressed by the annexed table, viz:

Blue metal from fifth operation, . .	0.789
Furnace waste, &c.—sand, . . .	0.108
" " bricks and clay, .	0.006
Oxygen derived from the air, . . .	0.097
	1.000

Two tons of the blue metal, or sulphide, are introduced carefully at the side and end doors above referred to, the temperature of the interior being somewhat reduced in order not to effect the fusion of the substance very readily. Care must likewise be taken that the bars of material are deposited within the furnace as perfect as possible, in order that they may present interstices for the flame and oxidizing current to pass through, which will thereby effect a better roasting than could be done, were the charge in small fragments. As the blue metal is brittle, it is customary to employ a kind of tool not very unlike a baker's peel, and which is worked by four persons for introducing it. It is kept at some distance from the bridge of the fire, as near this it would meet little of the flame; for this reason, about two and a half to three, or even four feet are reserved between the matter operated upon and the fire bridge. The heat applied in this case is during the first part of the operation is very moderate, but in proportion as the sulphur is eliminated, and the oxidation of the metals proceeds, it is increased, till in the end, it is raised suf-

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ficiently to bring the charge into a fluid state. By this routine, the iron, which alone had been oxidized during the roasting, is combined with the silica, and forms a fusible slag, which is removed after drawing off the matt of white metal.

The results of the charge are proportionally expressed in the annexed table:—

White metal for the eighth operation, .	0.588
Poor slag for the second operation, . .	0.103
Furnace waste for the fourth operation, .	0.008
Sulphurous acid, ...	0.124
	1.000

Eighth Operation.—This seems to be only a repetition of the preceding treatment, and is conducted in almost the same manner. It constitutes the last of the series called the *extra-process*, and yields a substance which, like that resulting from *operation four*, in the ordinary mode, is ready for the calcination by which the metal is obtained. The charge weighs about one ton and a half, and the time of working extends over seven or eight hours.

Two stages are observed in it: first, the roasting, by which a still further quantity of sulphur is expelled, and oxide of copper, with sesquioxide of iron, is produced; and, secondly, the fusion of the mass, as before detailed, by which any iron may be separated in the scoria. A reduction of some of the oxide of copper contained in the slag is likewise effected; when it comes in contact with the matt of rich white metal, it yields

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oxygen to the sulphur in combination, and gives rise to the formation of sulphurous acid and the precipitation of metallic copper.

White metal from the seventh division is usually employed alone, especially if a first quality of copper is to be produced; but when this is not the case, the matts procured from the fifth and sixth fusion are mixed with it in the ratio tabulated as under:

White metal of the seventh operation, .	0.712
" " " sixth " .	0.125
Red metal of the sixth operation, . .	0.034
Earthy matters from the sole, . . .	0.041
" " " brick and clay, . .	0.007
Oxygen from the atmosphere, . . .	0.081
	1.000

After the calcination is carried on with a gradual increase of temperature for about three hours and a half, the roasting is considered to be thoroughly performed; the fire is then urged, and the matter melted, and by this means a further quantity of sulphurous acid is liberated, in consequence of the action of the excess of oxide of copper in the slag upon the matt of sulphide of copper, by which the sulphur is oxidized, and a proportionate weight of metal precipitated. This precipitation of copper aids considerably in refining the matt of any portions of arsenic, tin, &c., which may be contained in it, and which it carries with it to the bottom. During the three hours and a half fusion, these changes are being instituted; and at the close, the charge is

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found separated into three distinct layers. Of these, the upper one consists of scoria, mixed with oxide of copper; the middle of the pure matt or regulus; and the under one, of bottoms, or an alloy of copper and tin, with an admixture of more or less matt. This is shown in the annexed statement of results:

Regulus of metal seven for the ninth operation,	0.528
" " six " " "	0.112
Cupreous base from seven, . . .	0.088
" " " six, . . .	0.020
Slags to be used again in the sixth operation,	0.118
Furnace waste " " fourth "	0.004
Copper sweepings, " " sixth "	0.002
Sulphurous acid, ...	0.128
	1.000*

Ninth Operation. At this stage of our description, we come back to the regular course of the smelting, which we left in order to describe a series of processes intended to bring into the final operations a class of substances which are continually accumulating about a smelting establishment. The last of these, which we have called number eight, has produced a result which may be mixed with the white metal from the fourth ope-

* I have quoted this entire description of the *extra process* from the excellent article on Copper, in Muspratt's Chemistry, because it is the fullest and most satisfactory account of the Welsh method of working up the residues from the furnaces, and the various cupreous matters which accumulate about a copper work. They are treated in this way, because they would not be advantageously smelted in the regular course. It is only employed when these matters have considerably accumulated.

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ration, or worked by itself for pig copper. Up to this stage, the smelter has been availing himself of two sets of reactions—that between sulphur and oxygen, and that between silica and oxide of iron. There has been a continual process of oxidation resulting in the formation of sulphates of the two metals. As the iron salt is more rapidly decomposed than that of copper, we have a quantity of oxide of iron in the bath of molten matter that fills the furnace. This oxide, having a strong affinity for silica at a high temperature, combines with that substance to form a fusible slag. The sulphate and oxide of copper reacting on the undecomposed sulphuret, produce sulphurous acid, which burns off, and sulphuret of copper, with a minimum degree of sulphuration, called by the smelters *white metal*, so that at this stage we may consider a large portion of the sulphur, and nearly all the iron, finally separated. It remains now to get rid of the remaining sulphur.

When no iron whatever is present, a simple roasting and smelting, under proper management, will dissipate the remaining sulphur. If, however, some iron remain, it will be necessary to add some silicious matter, in order to combine with the oxide of that metal, and thoroughly to purify the copper. As it is rarely the case that all the iron is separated in the fourth operation, it is customary to add to this charge some rich quartzose ores. Hence it will be seen that there are two objects to be accomplished in this process—one to roast the sulphur off by the direct action of the atmosphere, aided by the double decomposition going on between the sulphuret and oxide of copper; the other to get rid of iron by

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oxidating it and then combining it with silica. To accomplish these ends, the smelter divides this operation into four distinct stages. In the first, he roasts the material, by heating it, with free access of air; in the second and third, he manages the mutual decomposition of the oxide and sulphuret of copper; in the fourth, he produces metallic copper, effects the union of the oxide of iron with silica, and withdraws the slag.

The furnace in which this operation is performed, resembles the other smelting furnaces, having a side door, an end door, and a tap hole opposite the former. The charge is from three to three and a half tons of white metal and regulus, which are introduced in large masses, and piled up on the sole of the furnace. The openings are now closed and luted, and the heat is raised. The combustible gases, as they sweep over the mass of metal, gradually deprive it of much of its sulphur. If the furnace be watched at this time, little drops will appear to sweat out of the red hot pigs, and trickle down to the sole of the furnace. In this slow, piecemeal fusion, abundant opportunity is afforded for the oxidating action of the atmosphere. This first stage of the process lasts about four hours, and is completed when the whole charge has become liquid.

The second stage now begins. A seething, or boiling in fine bubbles, is now apparent throughout the entire bulk of the charge. Every now and then a brilliant spot is seen upon one of these little bubbles, and indicates the conversion of a portion of it into metallic copper. The reaction between the oxide and the sulphuret of copper is now going on.

This is completed in the third stage, which the work-

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man inaugurates by throwing open the doors, and admitting atmospheric air, taking care to keep the fire in such a condition that a partial closure of the openings will at any time raise the contents of the furnace to the necessary temperature. The first effect of the cold air is the formation of a consolidated film over the whole bath. Beneath this the action goes on violently, the confined gases causing rents in this surface layer, and throwing up new fluid from below. Presently, the cooled layer becomes so thick and tenacious that the gases cannot escape freely, but cause a great swelling of the mass, together with an agitation that effects the most thorough intermingling of the liquid contents. This evolution of sulphurous acid goes on for ten or twelve hours, at the end of which time the mass has cooled, stiffened, and become extremely porous on account of the inability of the gas to escape. The fire is now increased, the door closed, and the furnace brought to a bright red heat. The mass again becomes liquid, the gases are expelled, and the bath begins to boil with larger bubbles, so lustrous that it is scarcely possible to look at them. Six hours are usually taken up in this fusion, and at the end of that time, the sulphur is nearly all gone

All this time, the siliceous matters have been diffused throughout the mass without combining with the oxides, because the heat has been insufficient. In the fourth and last stage, however, the heat is raised to the highest point, and kept there till the process is ended. The silicate of iron now forms a fusible slag, which, being lighter than the copper, rises to the surface, and floats over the metallic bath. It is raked off at the end

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door, and the taphole being opened, the copper flows out into moulds. It is full of bubbles, brittle, with a coarse, granular fracture, the freshly broken surface being of a deep red color and full of cavities.

It is sometimes called *blistered copper*, from its blebby surface, and sometimes *pig copper*, from the forms in which it is moulded. The slag which is raked off from it, contains a large proportion of oxide of copper, and not a little of the same in a metallic state. The oxide is both in the form of a silicate and mechanically combined with the mass. This alone is worked down in the fourth operation.

In many furnaces, this process is divided in two. The *white metal*, of the fourth operation, is oftener sixty than seventy-three per cent., and its roasting in the furnace would take up too much time, and be imperfectly effected. It has been found advantageous, therefore, to tap out this substance at about the commencement of the third stage described above. As it flows from the furnace in a thin stream, it is, of course, freely exposed to the action of the air, and is very effectually roasted. Lying in its sand moulds, it speedily chills upon the surface; but in the interior of the pigs, the agitation of the liquid still goes on, giving rise to very interesting volcanic phenomena. Numerous small openings are made in the film, and the boiling matter from within is thrown out. It falls around the edges, making little irregular cones, which rapidly increase in height, till they resemble so many chimneys covering the pigs of regulus. Molten matters are shot out by the intestine commotion, far above their summits, and little

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streams of lava trickle down their sides. The geologist might gather some hints as to the action of volcanoes, by studying the phenomena of these little elevations. The regulus thus obtained, is often immediately charged back into the same furnace from which it was tapped out.

The copper obtained by this operation, is, as we have said, coarse and brittle, and unfit for the use of the mechanic. It still contains sulphur and other matters, which impair its tenacity. These are expelled in the final process, which we are now about to describe.

Tenth Operation. This process is called *refining* or toughening, and brings the copper to a marketable condition. It is performed in a furnace resembling the smelting furnace, except that the grate is larger, and the arch is higher. The former modification is necessary, because a greater heat is required than in the preceding operations, and the latter, in order to avoid risk of oxidation, which would take place rapidly under a low arch. If this accident were to happen, the refiner would witness what is called the *rising of the copper.* The film of oxide on the surface would first consolidate, then crack, and the liquid metal below would boil over the crust. Copper, in this condition, would be unfit to work, because it would not laminate. It requires a special treatment.

The pigs of copper, produced in the last operation, are charged into this furnace by means of a peel. These are carefully arranged so as to present a large surface to the action of the fire, and to allow the draught to pass through them. The amount of the charge varies from three to six tons, and in some places, it is said that ten tons have been worked. The heat is now kept up for

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about eighteen hours, during which time the copper is calcining, the metal having melted in the first six hours. The foreign metals and a good deal of the copper itself, are oxidated and combine with the silica, which is always present, in the shape of sand adhering to the pigs, and furnace waste. The oxide of copper assists the scorification of the other metals, which separate and rise to the surface with the slag. The heat is now increased awhile to ensure a proper fusion of the scoria, which is then raked off. This scoria is heavy and compact, of a dark or ruby red tint, due to the suboxide of copper, and filled with filaments and beads of metallic copper.

At this stage the metal is ready for refining. It is now *dry*, as the workmen term it, and contains a quantity of oxide of copper diffused through it. Its color is a deep red approaching to purple, its texture coarse, open and crystalline, and its tenacity very slight. At this time the refiner commences taking his *tests* or *assays*. He has a long handled ladle with a small bowl, which he dips into the melted metal. He then withdraws it, suffers it to harden upon the surface and plunges it into water to cool it. He cuts it partly through with a chisel, and then he breaks it, forming his opinion of the state of the copper by its color, its texture and its lustre.

If the metal were left uncovered at this high temperature, it would speedily absorb still more oxygen than is already combined with it. To prevent this, the refiner covers the surface with charcoal, which as it burns off absorbs the combined oxygen from the metallic bath. This action however, is confined to the surface of the metal, as is that of the billets of green wood which are now thrown on. To reach the centre of the charge,

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s tout poles of green wood are thrust below the surface of the metallic bath, where they burn at the expense of its oxygen. The ebullition produced by the escape of the gases, causes a thorough intermingling of the constituents of the bath, and brings every particle of it in contact with the deoxidizing agents. This *poling*, as it is called, continues for twenty minutes or half an hour. The refiner takes repeated tests during this process. If the broken surface is dull and of a purplish or brick red, he knows that there is still some oxide of copper mixed with the pure metal. When the refining is complete, the broken surface of the assay has a fine light red color, and a soft satiny lustre; as soon as this point is attained, the refiner orders the poles to be withdrawn. Should it be allowed to remain only a few minutes longer, an unfavorable change takes place. The copper absorbs carbon, and becomes even more brittle than before it was refined at all. The assay reveals this condition of the bath. Its color is a brilliant yellowish red, its fracture fibrous and striated, and its grain coarse. When this happens, the charcoal is pushed back and the doors of the furnace are thrown open to admit the air, which burns off the excess of carbon and restores the copper to its maleable condition. On the other hand, if the charcoal be not kept over the face of the bath, it absorbs oxygen from the air and returns to its *dry* state. The remedy for this is a fresh application of the green wood. In the former case, the workmen say that the copper has *gone too far* or that it is *over pitch*, in the latter it has *gone back* or is *under pitch*.

It often happens that a difficulty occurs in separating the foreign metals from the copper. This is overcome

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by the use of lead, which is an admirable scorifier and forms fusible compounds with the different metallic oxides, which rise to the surface and are raked off with the slag. To accomplish this, it is necessary to rabble the bath completely, so as to bring all the lead under the influence of the oxygen, that it may all be found in the slag. If any be allowed to remain in its metallic state, it has a very bad effect upon the subsequent rolling of the copper, in causing the scale to adhere to the surface and preventing the proper cleansing of the sheets.

The refining being completed, the men dip the copper out of a depression in the sole of the furnace just behind the end door. For this purpose they use iron ladles lined with clay. The metal is usually cast in ingots, in moulds made of copper. As soon as these ingots have consolidated, they are thrown into water. This gives them a slight film of sub-oxide which adds to the beauty of their appearance. If allowed to remain too long exposed to the air, before being plunged into water, they are coated with a scale of the black oxide which makes them rough and unsightly. When required for the rolling mill, the molten metal is cast into plates or bars.

Muspratt gives the following tables as representing the charge and its results.

Charge.

Coarse Copper, - - - - -	0.954
Earthy Matters, Sand, - - -	0.013
" " Brick and Clay, - -	0.021
Oxygen of the air, - - - -	0.012
	1.000

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Results.

Saleable Copper, - - -	0.908
Slag for Operation, four, - -	0.055
Furnace Waste, " - - -	0.022
Copper Sweepings, " - - -	0.002
Sulphurous Acid. - - - -	0.013
	1.000

In the foregoing account of the processes adopted at Swansea, I have chiefly followed Muspratt, who has given us the most recent and one of the fullest and most satisfactory descriptions of this elaborate system of smelting. It must not be supposed, however, that the routine there described, is servilely followed in all the establishments for copper smelting on the Welsh plan, much depends upon the kind of ore which is to be heated, much also upon the nature of the fuel. The *extra process*, intervening between the fourth and ninth operations, is often omitted, the substances to which it is chiefly devoted, being smelted in small quantities at the suitable stages of the regular process. At many works, the product of the fourth operation, or the first smelting after the calcination of the metal from the ore-furnace, has not reached the stage of white metal. In that case it undergoes a calcination to bring it up sufficiently for smelting so as to obtain regulus or black copper. In this country, where the ores smelted by this method under consideration, are richer, and rarely contain either arsenic, antimony or tin, the preliminary calcination is commonly omitted. The ores are thrown raw into the furnace, and calcination is performed upon the coarse

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metal obtained from them. This is then run down into white metal and the rest of the plan, with the exception of the extra process, goes on as we have described. Under some circumstances, the calcination of the coarse metal is omitted. Then, this product is introduced into a smelting furnace and subjected to roasting and fusion which produces *blue metal.* This, in its turn, is roasted and smelted in a similar manner, to produce white metal. There are still further modifications sometimes adopted, the whole depending upon the nature of the materials submitted to the smelter. The skill of the master workman is shown in adapting these processes to the requisitions of his particular work.

There is often a notable proportion of silver contained in the copper ores worked at Swansea. This is sometimes entirely neglected. There are works however, erected for the separation of the more precious metal. In these, various plans are pursued, which being foreign to our present subject, we shall not stop to describe. We will only state that in some establishments the process of liquation is adopted; in others amalgamation is used; while in others again, the metal is roasted with common salt to form a soluble double chloride of silver and sodium, from which the silver is precipitated by means of metallic copper.

NAPIER'S PROCESS.

The plan of copper smelting, patented by Napier, is said materially to shorten the operation and greatly to diminish its expense.

When Cornish ores are worked in this method, they

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are first thoroughly calcined in an ordinary furnace and then mixed with rich Cobre ores, or other sulphurets rich in copper, in such proportions that the iron and silica may combine, and the matt obtained may contain from 30 to 50 per cent. of copper. This mixture is fused and skimmed in precisely the same manner as the calcined ore in the second operation of the regular process. As soon as the face of the metal is cleaned, a quantity of soda-ash or salt cake is introduced, and well mixed with the mass. The alkaline sulphuret, thus formed, dissolves whatever antimony, tin or arsenic may be mingled with the mass, forming with them soluble double sulphurets. When salt cake is used, about 8 per cent. of charcoal is mixed with it, to reduce the sulphate of soda to a sulphide of sodium. As soon as the decomposition is complete, which is usually but a short time, the furnace is tapped and the matt cast into rectangular blocks. These are thrown as soon as they have solidified, into tanks filled with water in which they crumble to a fine powder. The water is now siphoned off and the sediments washed to disolve out the double sulphurets of antimony, tin and arsenic.

The residue is calcined to complete oxidation, an operation which is generally completed in 24 or 30 hours. The roasted metal is now mixed with coal or charcoal and an additional quantity of ore, rich in silica, but free from sulphur or arsenic, and smelted in the ordinary way. Reduction takes place and a slag is produced which contains but little copper.

When carbonates of copper or tile ore, containing a small percentage of earthy bases and a large amount of

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silica, are treated in this way, the iron scales from the rolling mill and forging hammer are added, in order to form a fusible slag. Rich iron scoria or carbonate of iron may be used instead of the scales, but all sesquioxides must be avoided, as they part with a portion of their oxygen which combines with the copper and deteriorates the product. If the slags are too stiff, they may be lightened by the addition of salt or quick lime.

BRANKART'S PROCESS.

Like Napier's, this plan combines the humid with the dry treatment. The rich ores from South America and Cuba are treated by this method, at the Red Jacket Copper Works in Neath, Glamorganshire. The ore is reduced to a fine powder, and then roasted in a reverberatory furnace till the sulphurets are oxidized to sulphates. The calcined ore is then thrown into large vats or tanks filled with water. In these the sulphates of copper and iron are dissolved, the supernatant liquor siphoned off into other vats containing scraps of old iron which precipitate metallic copper. When all the copper is thrown down, the iron salt may be crystallized out of the mother liquor after suitable concentration. The insoluble residue is dried, mixed with a fresh proportion of ore and again submitted to the process of calcination.—The copper which has been thrown down by the iron, is roasted, fused and cast into ingots.

RIVOT AND PHILLIP'S PROCESS.

The ore is roasted dead, that is to the expulsion of sulphuric as well as sulphurous acid, and the consequent

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conversion of all the sulphurets into oxides. When this has taken place, bars of iron are introduced, at this high temperature, these rapidly oxidate at the expense of the cupreous oxide, and form with the silica a fusible slag which is raked off, leaving a bath of metallic copper.

The objections to this process are that it uses a great deal of metallic iron, and that it does not accomplish the purification of the copper if tin, arsenic, or antimony are found in the ores.

DAVIES' PROCESS.

This is applicable only to oxides and carbonates of copper which contain no other metals than iron and manganese. These are mixed in such proportions that the silica of the ores may be to these oxides as five to seven. If silica be in excess, oxide of manganese is added, and if this oxide or that of iron be superabundant more silica is introduced. The whole being well mixed with coal, is then smelted to produce the metal.

BIRKMYRE'S PROCESS.

Copper pyrites is the ore treated according to this method. After being finely powdered and mixed with nitrate of soda, it is placed in trays and introduced into kilns resembling those commonly employed for roasting pyrites. While exposed to the heat, it is repeatedly stirred with a rake in order to bring every particle of it within the influence of the air that passes through the furnace. The nitrate of soda assists the atmosphere to oxidate the sulphur and its metallic bases, and the result of the operation when effectually performed is a

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mixture of the sulphates of iron, copper and soda, with undecomposed silicates. The soluble salts are leached out and the copper precipitated, as in Napier's process, by means of metallic iron.

DE SUSSEX'S PROCESS.

The patentee directs that the ores be so mixed as to contain about sixty per cent. of silica. Should there be more than this, fluor spar, lime or any other substance which will form fusible compounds with it, is added. Twenty-five pounds of finely burned charcoal, or of stone coal free from sulphur, for every five hundredweight of mixed ore are then incorporated with the charge, and the whole introduced into a reverberatory furnace. In three or four hours, most of the sulphur will be expelled, but to effect its entire separation, the temperature is to be lowered, and about five per cent. of alumina, magnesia or magnesian limestone, or if these cannot be had, of nitrate of potassa, soda, or lime to be intimately mixed with the charge. The heat is then increased to decompose sulphate of copper. The roasted ore, mixed with an equal weight of anthracite coal, and four parts of silicate of potash or soda for every ten parts of silica in the substance, is then melted to obtain the metal. The patentee suggests, if the roasting be insufficient to expel all the sulphuric acid, the remaining sulphate of copper be decomposed by digestion in a tank of ammoniacal water, which must, of course, contain exactly enough ammonia to decompose the unknown quantity of copper salt.

The whole plan is curiously unpractical.

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LOW'S PROCESS.

This is another method which could not be carried on by ordinary workmen with any reasonable prospect of success. The patentee proposes to employ a mixture of peroxide of manganese, 42 parts; plumbago, 8 parts; nitrate of potassa, soda, or lime, 2 parts; wood charcoal, or anthracite, 14 parts. While the fusion for matt is going on, 25 pounds of this mixture are added and rabbled thoroughly with the molten mass. The slag which rises is skimmed off, and a fresh quantity of the flux added, and the same operation repeated till the workman considers that the copper has advanced sufficiently to be tapped out for reduction in the smelting furnace.

OTHER PATENTED PROCESSES.

Parkes recommends that the mineral be roasted till a matt called *close regule* is formed, when iron is added in the proportion of a hundred weight to each two and a half tons of the above compound. The heat is then urged so as to keep the whole mass in perfect fusion for some time, and the metal is finally tapped out as *pimpled copper*. He also suggests the use of the refining process previous to *poling*, but it is objectionable on account of the probable bad effects of its oxide on the furnace bottoms.

Trueman and Cameron roast their sulphates, boil the calcined ore in a solution of caustic potash for six hours to separate the tin, arsenic and antimony. The residual ore is again roasted to produce an oxide which is mixed with a fresh portion of crude ore in the proper proportion to convert all its sulphur into sulphurous acid. The

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silica should be so proportioned to the iron as to form with the oxide of that metal a fusible slag, and either sand or cobbing must be added if silica be deficient. The mixture is fused in quantities of two and a half tons for every charge. Five hours after charging, the mass is well rabbled, then allowed to rest, the slags being skimmed as they rise to the surface. Another charge is then introduced and treated in the same manner, the furnace being tapped only at every second charge. This yields a rich sulphuret of copper free from iron, which furnishes copper of good quality when calcined and fused in the reducing furnace.

A second patent, granted to Trueman in 1852, proposes to treat the ores with an acid, and to precipitate copper from this solution with lime or its salts.

FRENCH METHOD OF COPPER SMELTING.

We have spoken, in a previous part of this work, of the ores of Chessy, near Lyons. They are red and blue, the former an oxide, the latter a carbonate of copper, mixed with a greater or less proportion of impurities. The red ores contain from 38 to 76, the blue from 20 to 36 per cent. of metallic copper. The impurities consist of susquioxide of iron and compounds of silica and alumina.

The furnace in which these ores are smelted is called by the French *fourneau a manche*. Its base is made of very solid masonry, strengthened by transverse bars of iron. The cavity is lined with a coating of very refractory material, cemented to the masonry in the form of an ellipse, and renewed every season. The two lateral

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faces are constructed of gneiss, and the front, called *fier-vende*, of rectangular iron plates, coated with fire-clay. The cavity is a rectangular parallelopiped about six feet long, five and a quarter broad, and three and a quarter deep. The sole is formed of a fire-brick made from Bourgogne clay and pulverized quartz. The tuyere has an orifice three inches in diameter, its muzzle being wrought and its bed cast iron. Opposite it is a platform made of clay firmly beaten, in which there is dug a crucible on a level with the sole of the furnace. It is coated with a mixture of clay and finely powdered charcoal, and from it passes an inclined canal leading to the receiver in which the fluid collects.

The ore is mixed so that its average content of copper shall be about 27 per cent. To this is added 5 per cent. of lime and some scoria. Every hour, 200 pounds of this mixture mingled with 150 pounds of coke are thrown into the furnace. As the fusion goes on, the melted metal and slag flow out together into the crucible, when the slag is skimmed off. As soon as the metal fills the basin, it is run into the receptacle. A little water sprinkled over the surface of the metal causes the formation of a skin or crust which is removed from the bath. The continued repetition of this process converts the entire bath into round cakes about an inch thick. The metal is run off from the crucible twice in twenty-four hours, and the entire daily product is about fourteen hundred weight.

The slags differ in their composition according to their color or to the source from which they are taken. A little scoria unavoidably runs over into the receiver, and

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this differs from that which is skimmed from the crucible in containing no lime. It is essentially a silicate of iron mixed with a little sulphur and other impurities, containing about 4.5 per cent. of copper, together with a little metallic iron. It is formed by the action of the air upon the metals of the bath, and the subsequent reaction of the oxides upon the silicious matter of which the receiver is composed. This corrosion renders necessary the repeated renewal of the walls of the receptacle, which must be repaired weekly. The slags which are skimmed from the crucible are of three colors, blue, black and red. Of these the *blue* contain the least oxide of copper, and are formed when lime is present in due proportion. The *black* slags contain more copper, and are produced when lime is deficient, or when black slag from a previous operation has been added in too great quantity. *Red* slags are silicates of iron and copper, and are formed when the silica is not properly proportioned to the earthy bases, or when the heat is too high, melting the slags before the carbon has time to reduce the suboxide to metallic copper. In the first instance, these scoria are converted into the black variety by the addition of lime; in the second it is only necessary to reduce the temperature of the furnace.

The black copper obtained from this furnace varies in composition. That from which the black slags have been taken contains from 7 to 8 per cent. of iron. Like all copper obtained from blast furnaces, in every instance it is more or less contaminated with iron. The different layers or discs, which have been removed from the same bath vary in their composition, the lower strata being

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richer in copper on account of the greater specific gravity of that metal.

The average composition of this black copper, as determined by the means of several analysis by M. Margerin, is stated in the following table:

Copper,	89.30
Iron,	6.50
Protoxide of Iron,	2.40
Silica,	1.30
Sulphur,	0.34
Loss,	0.16
	100.00

This copper is refined in a *spleiss-ofen*, which, together with the process, will be presently described.

SMELTING OF THE MANSFELD COPPER SCHISTS.

The copper schists of Mansfeld are, as we have already said, poor in copper, but their great abundance enables the metallurgist to extract that metal from them with profit to himself. The process adopted is very ingenious, advantage being taken of the bituminous matters diffused throughout the mass.

The first operation is the calcination of the ore in mounds containing each about a hundred. The broken shales are interstratified with wood, and the combustion is carried on partly by this fuel and partly by the bitumen of the slate. These heaps continue burning fifteen or twenty weeks, at the end of which time the carbonaceous matters are consumed, much of the sulphur expelled as

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sulphurous acid and the metals generally oxidated. The calcined ore is friable, yellowish-gray, and about one-tenth lighter than it was before the operation. In the Lower Harz, the heaps are so arranged as to collect and preserve the sulphur.

The calcined ore is mixed with from six to twenty per cent. of fluor spar, some slag (containing copper) obtained from a previous operation, and some copper schist containing carbonate of lime. An ordinary charge contains twenty hundredweight of ferruginous, fourteen of calcareous and six of argillaceous copper schist, mixed with three of fluor spar and three of rich slag. The time of working this is about fifteen hours, and the product about one-tenth of its weight of copper matt, containing from thirty to forty per cent. of metallic copper.

The other metals present in the ores, nickel, cobalt and silver, together with zinc and iron, are found in this matt in the state of sulphides. The subsequent treatment of this matt depends upon the quantity of copper it contains. When rich, it is roasted five or six times and then smelted into black copper. When it contains no more than twenty or thirty per cent. of copper, the cakes of matt, alternated with brushwood, are roasted three successive times in kilns, the product being turned over after each calcination. The charge in this instance weighs three tons, and the operation occupies four weeks. The next process consists in the fusion of this roasted matt in a cupola, the result being a rich product called *spurstein*, containing from fifty to sixty per cent. of copper. This is mixed with material from the first

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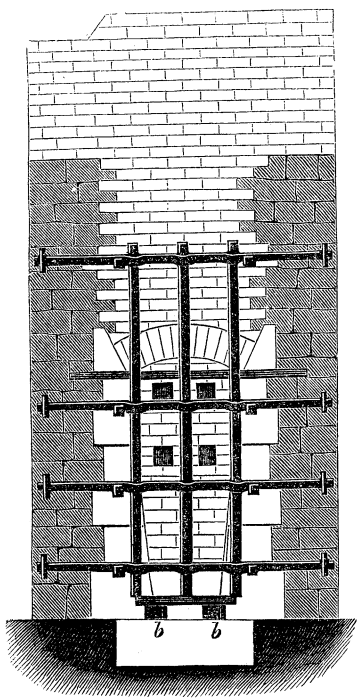
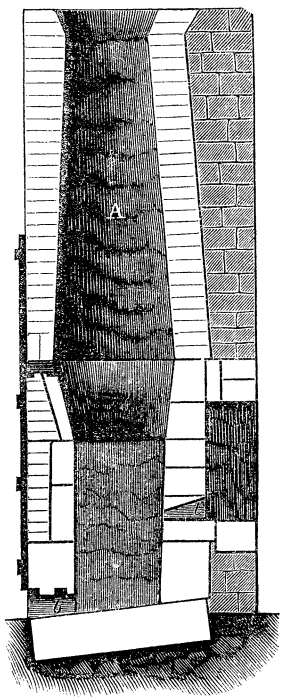
smelting, and roasted six times consecutively during a period of seven or eight weeks. The fuel consists of brushwood and charcoal, which are interstratified with

Fig. 11.



BLAST FURNACE. ELEVATION.
b b. Exit openings.

Fig. 12.



BLAST FURNACE.
A. Shaft.

the matt, the air being admitted to the lower part of the mass by channels opening inwardly at the bottom of the kiln. The kiln is built of stone, and consists of six

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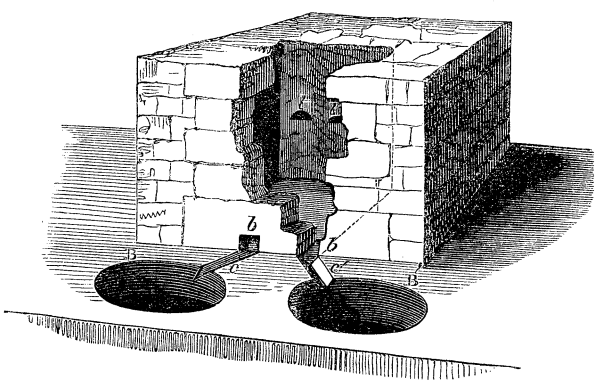
compartments, so arranged that the charge in one of them shall not mix with that in the adjoining one. The process is a continuous one, the roasted matt of the first compartment being introduced into the second, with the same arrangement of brushwood and charcoal, then into the third, and so on till the process is fully completed in the sixth. The *gahrrost*, as the Germans call the resulting product, resembles in color red copper ore, with an occasional bluish-gray tint. It is brittle and contains some reduced copper as well as sulphate and oxide of that metal. To separate the sulphate, it is lixiviated in a descending series of vats, so arranged

Fig. 13.



BLAST FURNACE.

B B, basins, *b* tap-door, *c c* channel to conduct metals to furnace, *t t* tuyeres.

that the solution drawn off from one shall pass through the next below in regular succession, till it becomes so concentrated that it can be crystallized with very little

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evaporation. Sometimes this process is carried on after each roasting in the compartments of the kiln producing the *gahrrost*. The calcined and lixiviated matt is generally melted with one-fourth its weight of lixiviated matt from the first fusion, and, when this is of good quality, one-sixth to one-tenth its weight of rich copper slags, with sufficient charcoal and coke. This mixture is smelted in the cupola furnace in quantities of three or four tons, the operation occupying twenty-four hours. The results are black copper and slags of variable richness; the metal, owing to its greater specific gravity, sinking to the bottom of the crucible, and being removed in cakes, as before described. The slag is subsequently roasted with matt and smelted to extract its copper. The black copper is by no means pure, since it contains the various metals already mentioned as present in the ore. Of these, silver being the most important, is separated by a special process.

This is usually what is known by the name of *liquation*, though sometimes the precious metal is separated from the *gahrrost* by amalgamation. The process of liquation depends upon the low fusion-point of an alloy of silver with lead or zinc. Three parts of the black copper are fused with ten or twelve parts of lead or an equivalent proportion of litharge rich in silver. The alloy is run into moulds, where it is rapidly cooled by water, and lifted out in discs of an inch or less in thickness. These are then placed on the hearth of a furnace of peculiar construction, and heated gradually. The melting point of the lead alloy being far below that of copper, the silver-lead flows out and is collected. When no more

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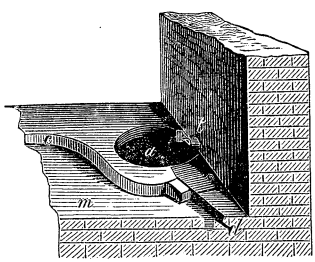
oozes from the cakes, these are transferred to another furnace where they are subjected to a higher heat, by which more silver is recovered and the cakes left in a purer state. They still, however, contain a little silver and some lead, but the latter metal is entirely removed in the subsequent operation of refining.

The refining is carried on either in a *spleiss-ofen* (split-hearth furnace) or in the arrangement figured below. The *spleiss-ofen* is a furnace of peculiar construction, consisting of a sole communicating by separate channels with two basins into which the copper flows. These, the *split-hearths*, are connected with one another by a canal. The channels leading from the

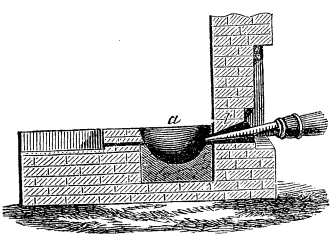
Fig. 14.



REFINING FURNACE.

a Crucible. *c* Iron curb to prevent waste of charcoal. *d* Charcoal for slag. *t* Tuyeres.

Fig. 15.



SUCTION OF REFINING FURNACE.

a Crucible. *t* Tuyeres.

main hearth are provided with fire bricks to contract them till the discharge of metal is allowed. The main hearth is elliptical in form, eight feet long by six and a-half wide, and is made of a mixture of coal-dust and clay well beaten into a clay bottom, resting upon a bed

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of brick-work, the whole being supported by a slag bottom built on a foundation of gneiss. Two tuyeres, through which the blast from the bellows is thrown, complete the arrangement. The charge for this furnace, amounting to sixty hundredweight, consisting of black copper mixed with granular copper and copper of cementation, is introduced through the working-door and spread over the sole of the furnace. As soon as it has melted, the bellows begin to play over the surface of the bath. Soon a layer of cinders and scoria collects upon the face of the metal. This is skimmed off. A second and third layer follow, and each is skimmed off as soon as it forms. When no more slag is formed, the fire is increased and the liquid begins to boil, continuing to do so for three-quarters of an hour or an hour, after which it remains tranquil although the heat be kept up. In about three-quarters of an hour after the boiling has ceased, the refining is finished; the furnace is then tapped and the charge received in the basin. At this time a reddish mist hovers over the surface. This is composed of extremely small globules revolving with great velocity upon their axes. They are composed of a nucleus of pure metal covered with a layer of protoxide. The Germans collect them and use them as sand for letters. The copper is removed in disks by sprinkling water upon the surface and lifting off the cooled layer. It is known in commerce as *rosette copper*.

The liquated copper is treated in a furnace of simple construction. It consists of a hemispherical crucible, sixteen inches in diameter, rendered fire-proof by a

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coating composed of two parts of powdered charcoal and one of fire-clay, into the cavity of which open the tuyeres. When it is used, the crucible is first filled with lighted charcoal, then more fuel is introduced, and with it pieces of black copper which are deposited opposite the tuyere. The blast is gradually admitted, and as soon as the metal of the first charge has been fused, another supply of the black copper, mixed with sufficient charcoal to effect the reduction, is put in. This process of repeated charging is continued till the crucible is full. The slag which is formed during this process flows out through a channel provided for it into a receiver, where most of the copper it contains settles to the bottom. As soon as the crucible is full, the copper is tested by introducing an iron proof-rod and withdrawing a scale of metal, which is immediately immersed in cold water. When the assay is brownish-red on the outside, copper-red within, thin and brittle, the refining is considered finished. The blast is then cut off, and the iron and slag raked from the surface of the metal, which is removed in the usual way with the aid of cold water, till the whole charge is converted into rosettes.

The charge for an ordinary furnace of this kind is two and a-quarter or two and a-half hundredweight, though larger furnaces will work up seven hundredweight. In the first instance, the refining occupies three-quarters of an hour, while in the second two hours are required. The object of the process is to oxidate the more readily scorified metals, lead, iron, nickel, &c., and to run them off in the slag. This is not fully accomplished, as the refined copper always retains ap-

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preciable quantities of these impurities. The slags vary in color at the different steps of the operation. At first they are greenish, containing much oxide of iron but little copper. Towards the close of the operation, however, they become heavier and assume a deep red color, owing to the presence of suboxide of copper. These are of course worked over again in the process for obtaining black copper.

These rosettes are never pure enough for making rolled copper. They are accordingly submitted to another operation, which consists in melting them under cover of charcoal to absorb their excess of oxygen. Tests are frequently taken and the process is continued till the full malleability is obtained. When the action of the charcoal has been so prolonged as to form a carburet, the bath is uncovered and the bellows compelled to play over it, in order to burn off the excess of carbon as carbonic acid.

Copper is sent to market in various forms, the most common of which is the ingot. *Bean and feathered shot* are obtained by pouring the refined metal into an iron perforated ladle placed over water. If the water be hot, the copper assumes the form of rounded grains which are known as *bean shot;* if it be cold, the droppings of metal will be flattened, irregular and branching, and to these has been given the name of *feathered shot.* Japanned copper is made by casting the refined in small ingots, which are thrown, while quite hot, into cold water. By this treatment, the metal acquires a fine red coating of suboxide which gives it value in the eyes of the orientals to whom it is exported from England.

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CHAPTER VI.

ALLOYS OF COPPER.

THE alloys of copper are both numerous and valuable. The great majority of all the alloys in common use contain copper as a principal ingredient. In the following description of these compounds, brevity is aimed at; those which possess merely scientific interest will be only glanced at or entirely neglected.

With the metals of the alkalies and of the alkaline earths, copper forms alloys not often met with. *Potassium* and *sodium* have been thought to increase the malleability of copper. Dumas describes an alloy of this kind composed of copper 99.12, potassium 0.38, calcium 0.33 and iron 0.17 in the hundred parts.

That copper combines with *aluminium* has long been known, for alumina has been obtained from some varieties of commercial copper. The recent researches of Sainte-Claire Deville have given us a more definite knowledge of these substances. Some of these alloys are light, hard and white, others yellow. Very small proportions diminish materially the malleability of aluminium, communicate to it a blueish tinge and render it liable to blacken by exposure to the air. On the other hand, small proportions of aluminium harden copper without materially affecting its malleability, and give it the color of different varieties of gold. By combining

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100 parts of copper with 10 of aluminium, an alloy is obtained, harder than that used for money, malleable, resembling in color the pale gold of the jewelers and taking a brilliant polish. The alloy of 100 parts of copper with 5 of aluminium is softer, approaches more nearly in tint to pure gold, and is also susceptible of a high polish.

With *manganese* and *cobalt*, copper also forms alloys under favorable circumstances. *Iron* is difficult to alloy with it, and generally renders it brittle and coarse in the grain. I have, however, made an alloy of copper and iron which was quite malleable. Cast iron is rendered brittle by copper. I recently received for analysis a cast iron containing copper which was so brittle that it was easily reduced to powder in a common iron mortar. Rinman recommends a mixture of 100 parts of gray cast iron with 5 of copper as a suitable material for anvils, on account of its hardness.

With *arsenic*, copper forms a white alloy, sometimes used for thermometer and barometer scales, dials, &c. It is composed of 9 parts of copper and 1 of arsenic. To attain this proportion, however, it is necessary to introduce $3\frac{1}{2}$ parts of the latter metal before fusion, which operation is conducted under salt, in a closed crucible.

The most important of all the alloys of copper are those which it forms with zinc, tin, lead and nickel; and these we now proceed to describe under their commercial titles.

Brass.—This is an alloy of considerable antiquity, though not so old as bronze. The first writer who

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speaks distinctly of it is Aristotle. In the time of Augustus, cadmia is spoken of, and we are informed that it was used in the manufacture of *aurichalcum*, as brass was called.

Though all alloys of copper and zinc are known by the generic name, brass, yet there are numerous varieties which have received different names. Almost every variety of tint between the red of copper and the white of zinc, can be communicated to these alloys by the modification of the properties of the two metals employed. Although the metals named are the only essential constituents of brass, yet this alloy often contains others, added for some real or fancied improvement in working, or accidentally present from impurities in the constituents. Lead, tin and antimony are the most common of these foreign bodies. Iron is sometimes present and is always injurious. It does not combine chemically with the alloy except in very minute proportions, but is found disseminated through the mass in small magnetic particles. It makes the alloy hard and dull, diminishes its tenacity and malleability, and renders it liable to tarnish and rust when exposed to the air. The source of this contamination may be either the calamine from which brass is often made, or the old brass which is melted over.

Tin and lead are not so injurious. Their presence is even considered beneficial in some particulars. They usually come from old brass which has been tinned or soldered, or from rosette copper, from which the lead, employed to separate the silver by liquation, has not been completely separated in the subsequent process of refining. "This brass, although it is harder and more

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brittle than the ordinary kind, is more easily worked under the lathe, but that which is dry is generally preferred by the turner; it may be welded together, and the junction is not easily broken; in addition, it can be cut with a chisel, sawn, and penetrated with exactness."* The following table expresses the composition of several varieties of this kind of brass. No. 1 is a cast of brass of uncertain origin; 2 the plate brass of Jemappes; 3 the sheet brass of Stolberg, near Aix-la-Chapelle; 4 cast brass of Stolberg:

	1	2	3	4
Copper, ...	61.6	64.6	64.8	65.8
Zinc, ...	35.3	33.7	32.8	31.8
Lead, ...	2.9	1.4	2.0	2.2
Tin, ...	0.2	0.2	0.4	0.2
	100.0	100.0	100.0	100.0

The proportions generally thought to produce the finest brass, are 63 of copper to 32 of zinc. These are, however, continually varied in practice as may be seen by the foregoing analyses. Sometimes the variation is the result of accident, though it is frequently made intentionally, with a view of providing for some particular contingency. "Thus, when a rich alloy of considerable tenacity is required, the zinc is reduced to 25 per cent., while with one of little resisting power, 50 per cent. of zinc may be used, and should a hard and very brittle compound be desired, the zinc is raised to 60 per cent."†

Gilding metal is more variable in its composition, though resembling in the main the variety just described.

* Muspratt's Chemistry, i. 535, article COPPER. † Ibid.

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It should be very close-grained and compact, so that none of the gold will be obscured by the shining through of a duller metal. The following table sufficiently expresses the varying composition of this alloy:

	1	2	3	4	5
Copper, ...	63.70	64.45	78.48	78.84	82.3
Zinc, ...	33.55	32.44	17.22	17.31	17.5
Tin, ...	2.50	0.25	2.87	0.96	0.2
Lead, ...	0.25	2.86	1.43	2.87	0.0
	100.00	100.00	100.00	100.00	100.0

The densities of Nos. 1 and 2 are 8.395 and 8.542 respectively, and they are considered by D'Arcet to be the best adapted to the purposes of the jeweler. The quantity of copper is often increased to 90 or 95 per cent., when the composition is analogous to chrysocolla, and is known as *gilding metal.** The other brasses in the table resemble Bath metal, pinchbeck, similor and Mannheim gold.

Although lead and tin do not deteriorate the varieties of brass we have just been considering, they would be seriously detrimental to those which are to be hammered, rolled or drawn, did they occur in large quantities. The following table expresses the results of several analyses of brass wire. No. 1 is English brass wire; 2 Augsburg wire; 3 wire made at Neustadt-Ebenwald, near Berlin:

* According to analysis, the composition of chrysocolla is:

Copper, . . .	90.0
Zinc, ...	7.9
Lead, ...	1.6
	99.5

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	1	2	3	4	5
Copper, ...	70.29	71.89	70.16	66.2	67.0
Zinc, ...	29.26	27.63	27.45	33.0	32.0
Lead, ...	0.28		0.20		0.5
Tin, ...	0.17	0.85	0.79	.08	
Antimony, . . .					.05
	100.00	100.37	98.60	100.0	100.0

Malleable brass or *yellow metal*, intended to work well under the roller or hammer, should approach as nearly as possible to the constitution of 70 of copper to 30 of zinc. The sheet brass of Romilly contains, by analysis, 70.1 of copper and 29.9 of zinc.

The brass used for machinery and locomotives in England is composed according to the following table:

Copper, . . .	74.5
Zinc, ...	25.0
Lead, . . .	0.5
	100.0

Its fracture is of a fine yellow color, but its malleability is inferred to those varieties in which the proportion of zinc is smaller.

The usual manner of expressing the composition of an alloy among brass founders, is to name simply the zinc, the quantity of copper being always taken as a pound. The following descriptions of the composition of different varieties of brass will be given in this method rather than the centesimal.

TRUE BRASS is formed of two parts of copper and one of zinc, but in this as in all the other alloys of copper

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and zinc, more of the inferior metal, owing to its greater volatility, must be added in order to obtain this proportion. *Muntz's metal* is made with $10\frac{2}{3}$ ounces of zinc to the pound of copper, his sheathing with from 9 to 16 ounces, according to Muspratt. *Bristol brass*, and those varieties generally which bear soldering, contain less zinc. The formula for Bristol brass, given by Muspratt, is 6 ounces of zinc to the pound of copper.

When *chrysocolla* is formed, or when it is desired to give the brass the property of casting well, from an eighth to a half ounce of zinc is alloyed with each pound of copper. The two metals, however, are not alloyed directly, but the result is obtained by fusing 4 ounces or less of brass with a pound of copper. *Gilding metal* is made in the same manner, so as to obtain the proportion of an ounce or an ounce and a quarter to the pound.

Prince's metal, or Prince Rupert's metal, contains about equal parts of the two metals. *Mannheim gold* contains 3 or 4 ounces of zinc to the pound. It is said to be made by melting separately 3 parts of copper and 1 of zinc, and then suddenly incorporating them by stirring. *Red brass*, or *tombak*, as it is called by some, has a great preponderance of copper, containing from 5 ounces of zinc down to $\frac{1}{4}$ ounce of zinc to the pound. At Hegermühl, 11 parts of copper are alloyed with 2 of zinc to make a red brass, which is afterwards rolled into sheets. At Nürnberg, *Dutch foil* is made from a similar alloy. *Pinchbeck* is made of 2 parts of copper and 1 of yellow brass. *Similor* is made of 28 parts of copper, 12 of yellow brass, and 3 of tin. *Bath metal* consists of 32 parts of copper and 9 of zinc.

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Brass solder, or *hard solder*, is made by melting together 2 parts of brass with 1 of zinc, and a little tin. When the solder is required to be very strong, as for brass tubes that are to be drawn, one-third less zinc is used. The *platin* of the Birmingham button-maker is made of 8 parts of brass and 5 of zinc. Cast white metal buttons are made of 32 parts of brass, 4 of zinc, and 2 of tin. *Mosaic gold*, according to the specifications of Parker & Hamilton's patent, consists of 100 parts of copper to 52 or 55 of zinc.

Brass may be made either by the direct combination of the pure metal, or by the action of copper on a mixture of zinc ore and charcoal at a sufficiently high temperature. The latter method is by far the most ancient, and by it brass was made long before metallic zinc was known. When an ore of zinc is employed, it should be free from sulphur and from silicate of zinc, and should also be well calcined in order to facilitate the reduction of the metal. To accomplish this, the calamine is roasted in heaps, alternate layers of ore and charcoal being erected into a mound, the base of which is composed of billets of wood. It is then ground, sifted and mixed with charcoal. The pots which are to be used in the manufacture are first heated in a furnace, then the mixture of calamine and charcoal is introduced into them, and the necessary quantity of rosette or grain copper forced into the mixture by a few blows of a mallet or hammer. The surface is then covered with a layer of the mixture, the pots returned to the kiln and surrounded with fuel. The furnace is now closed, and the heat kept up for six or seven hours, at the end of which

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time, the contents of the pots are at a white heat. At the close of this period the heat is pushed, till the fumes of volatilizing zinc, indicating the reduction and fusion of this metal, make their appearance. The heat is now diminished to prevent the too rapid melting of the copper, and to ensure the thorough mixture of the two metals. For three or four hours the heat is nicely regulated, at the end of which time, the combination is complete.

The first result of this fusion is *arcot*, a brass containing less than the standard proportion of zinc. This is again fused with an additional quantity of charcoal mixture to make the ordinary commercial brass.

The other method possesses advantages over the one just described. By fusing the metals, not only are fuel and labor, but a larger product is obtained in a given time. This method of direct fusion is, however, attended with difficulties. Not the least of these is the great affinity of zinc for oxygen, in consequence of which it not only loses its power of combining with copper, but is rapidly volatilized, causing considerable loss. For this reason, the operator is compelled to employ much larger proportions of zinc than he wishes to have in his finished alloy. This loss may be diminished by covering the surface of the metallic bath with suitable fluxes, and thus prevcnting this unfavorable action of the atmosphere. Lord Rosse is said to have made the greatest improvements in this direction. By deepening the kiln and keeping the surface of the bath constantly covered with a layer of powdered charcoal two inches thick, it is pretended the loss of zinc is not more than 0.56 per cent. or $\frac{1}{180}$ of the entire amount of that metal.

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How great this loss usually is may be learned from Holzapffel's careful experiments. His loss was about the thirtieth of the whole alloy. He fused twenty-four pounds of copper, and then gradually introduced twelve pounds of zinc. The surface of the metal was then covered with glass and left until the contents of the pot were in perfect fusion. The alloy thus obtained, instead of $33\frac{1}{3}$ of zinc, contained only $31\frac{1}{4}$. On remelting the alloy, it continued to lose zinc, till after the sixth operation that metal was reduced to $4\frac{5}{8}$ ounces to the pound.

The specific gravity of brass is greater than the mean density of its constituents. Sheet brass varies from 8.52 to 8.62; brass wire from 8.49 to 8.73.

GERMAN SILVER.—This alloy has been known by various names, as British plate, Argentan, Cuivre blanc, Maillechort, Neusilber, Weisskupfer, &c. It is an alloy of copper with nickel and other metals. The Chinese have long used it under the name of *pakfong*, or white metal, but in Europe it has only been known for the last hundred years. It was first made in Germany, by smelting ore found at Hilburghausen, near Sahl, in Henneberg. Referstein's analysis of the original compound gave the following results:—

Copper, ...	40.4
Nickel, ...	31.6
Zinc, ...	25.4
Tin, ...	2.6
	100.0

The Chinese pakfong always contains iron, which

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gives a brighter color to the alloy and renders it more compact, though it also makes it hard and brittle. Nickel being rather a raw metal, attempts have been made to diminish it by substituting zinc for it. These are successful only when the zinc is limited to a certain point, beyond which, if any be added, the compound though looking well at first, assumes the hue of pale brass. The following table, copied from Muspratt, expresses the composition of the varieties of this alloy:—

	1	2	3	4	5	6	7	8	9	10	11
Copper, .	43.8	40.4	53.4	50.0	65.4	60.0	67.0	59.2	55 0	51.6	45.7
Nickel,..	15.6	31.6	17.5	18.7	16.8	20.0	20.0	14.8	20.6	25.8	34.3
Zinc,....	40.6	25.4	29.1	31.3	13.4	20.0	20.0	26.0	24.4	22.6	20.0
Iron, ...	....	2.6	....	....	3.4	....	....	....	....	....	....
Lead,...	....	....	....	....	....	....	3.0	....	....	....	....
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Numbers 1 and 2 are analyses of Chinese pakfong, the latter being very superior in color and taking a high polish. Nos. 3 and 4 are alloys, prepared by Frick, resembling a silver about 18 carats fine. They are hard, but tough and ductile, and become soft by immersing in cold water. No. 5 is *Maillechort*, made in Paris. It is quite malleable and takes a high polish when heated; it loses twelve per cent. and becomes whiter. Nos. 6 and 7 are alloys recommended by Gersdorff of Vienna, the first for forks and such articles, the second for such objects as require soldering. No 8 is, according to Mr. Topping, of London, the commonest of German silver, fit only for wire and articles of inferior value. If the quantity of nickel is brought much below this, the alloy will be little better than pale brass, and will tarnish rapidly. The same authority highly recommends No. 9,

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as being very beautiful, and little inferior to silver that is nearly standard. No. 11 is the richest alloy that can be made without injuring the mechanical properties of the metal.

Tutenag is an alloy in frequent use among the Chinese. It is very fusible, but hard, and not easily rolled, and therefore answers better for castings. Its composition is—

Copper, ...	40.7
Nickel, ...	17.4
Zinc, ...	36.9
	100.0

This alloy is prepared, like brass, in pots or crucibles, and much of the zinc is lost. The only way in which the bad effects of this can be obviated, is by taking a larger quantity of the volatile metal, to allow for the waste. The metals are usually stratified in the crucibles, the lowermost and topmost layers being copper, and the whole being covered with charcoal powder or pulverized glass. When fused, the metals should be thoroughly incorporated by stirring with a porcelain rod. When fragments of German silver are fused a second time, more zinc must be added in order to make up the loss just alluded to.

Bronze.—This compound is essentially an alloy of tin and copper, though other metals are introduced in practice. It is one of the oldest known alloys. The so-called copper tools found in Egyptian quarries, which have elicited so much ignorant admiration from anti-

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quarians, are in reality composed of tempered bronze. The ancient swords were made of this alloy. A sword found in the peat moss of the Somme, contained of copper 87.47, tin 12.53. Another, found near Abbeville, was composed of 85 copper to 15 tin, and another of 90 of copper to 10 of tin. The bronze springs of the balistæ contained 97 of copper and 3 of tin.

The application of this compound to the casting of statues, also dates from a very remote antiquity. It was, however, first brought to something like perfection by Theodorus and Rœcus, of Samos, about seven hundred years before the Christian era. In the reign of Alexander of Macedon, the celebrated artist, Lysippus, gave a new impulse to this department of art, by his improvements in moulding. He made six hundred bronze statues of his great patron, and this wholesale manufacture gave rise to Pliny's sneer—"The mob of Alexander." Colossal statues were afterwards made from this same metal, the most celebrated of these being the well known Colossus of Rhodes. Some idea may be formed of the great demand for bronzes, from the fact that the Roman Consul, Mutianus, found three thousand bronze statues at Athens, eight thousand at Rhodes, and as many at Olympia and Delphi, though from the latter place a great number had been removed before his arrival.

It must not be supposed, however, that the ancients possessed the skill of the moderns in the management of this metal. Having no means of ascertaining with certainty the actual composition of these alloys, they could not provide against the oxidation of the tin, and

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consequent refining of copper, which is one of the great difficulties in the working of this alloy. Consequently, analysis has shown that their bronzes are of very variable composition, some of them containing the proper quantity of tin, and others being nearly pure copper.

Indeed, this difficulty has not always been overcome in modern works. The statue of Desaix, in the Place Dauphiné, and the great column in the Place Vendome, are signal instances of failure in this respect. On analyzing, separately, specimens taken from the bas-reliefs of the pedestal of this column, from the shaft, and from the capital, it was found that the first contained six per cent. of tin, the second much less, and the third only 0.21 per cent., being nearly pure copper. Hence, it appears that the unskilful founder had gone on refining the copper by the oxidation of the tin until he had exhausted his copper, and that he had then worked up the refuse scoriæ in the upper part of the column. The cannons which the government furnished him were composed of

Copper, . . .	89.360
Tin, ...	10.040
Lead, ...	0.102
Silver, zinc, iron, and loss,	0.498
	100.000

The moulding of the several bas-reliefs was so badly done that not less than seventy tons of bronze was removed by the chisellers employed to repair the faults.

Bronze is more fusible than copper, and, as in the last described alloy, its density is greater than the mean of its constituents. This, however, does not appear when the specific gravity is taken of bronze in bulk,

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since its vesicular structure interferes with the accurate estimation of its density. For this reason, the experiment must be performed, not upon a solid piece of the alloy, but upon its fine powder. Some of its forms are malleable, especially that composed of eighty-five parts of copper and fifteen of tin. Other varieties, made of different proportions of the constituent metals, may acquire malleability by tempering, which lessens their density and hardness, and sometimes renders them more tenacious. The following table exhibits, at a glance, the effect of this process upon different bronzes:

Composition of alloy—Copper,	95	90	85	80	75
" " Tin,	5	10	15	20	25
	100	100	100	100	100
Density before tempering,	7.92	8.08	8.46	8.67	8.57
" after "	7.89	8.00	8.35	8.52	8.31
Hardness before tempering,	100	100	100	100	100
" after "	99	98	96	92	91
Sample ¾ line in thickness, before tempering, tenacity,	80	66	48	50	70
" " " " after " "	100	100	100	100	100
Sample 8 lines thick, before tempering, tenacity,	100	100	80	80	100
" " " after " "	75	78	100	100	35

We have already alluded to the difference made in samples of bronze by the oxidation of zinc. The following table expresses the change effected by a series of successive fusions.

Number of fusions.	Weight of ingot in ounces.	Loss per cent.	Specific gravity.	Composition. Copper.	Tin.
1	268	1.2	8.565	90.4	9.6
2	236	1.6	8.460	90.7	9.3
3	204	2.1	8.386	91.7	8.3
4	172	2.5	8.478	92.8	7.2
5	140	2.6	8.529	93.7	6.3
6	104	3.0	8.500	95.0	5.0

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It is not, however, only the loss in weight, and the change consequent upon the diminution of the proportion of tin which measures the deterioration of the bronze. There remains mingled with it a greater or less quantity of the oxidized metals, impairing its tenacity and its capacity for wear. This is easily remedied by fusing it with the necessary quantity of tin and some charcoal, and, if required, by poling the bath as in the refining of copper.

Another peculiarity of bronze, when cast in sand moulds, especially if they be large, is, that shortly after casting, a jet of liquid metal flows out from the interior, either at the sides or the upper surface of the metal. It has been suggested, to account for this phenomena, that the first part of the alloy which comes in contact with the walls of the mould, condenses, contracts, and displaces the new-expanded molten metal within, which exudes laterally when the pressure of the metal from above is very great, but rises, if this weight is not sufficient to keep it down. The escaping metal is richer in tin than the solidified alloy.

The effect of introducing other metals besides tin, is often beneficial. *Iron* is thought to improve the character of the alloy, rendering it harder and tougher, as well as less fusible. The latter quality is an advantage when casting in sand moulds, as such an alloy is less liable to the formation of cavities, since the matter immediately solidifies upon coming in contact with the walls of the moulds, and does not allow the entrance of air into the fluid mass, as takes place with the ordinary bronze.* *Zinc* is held to produce similar results, and

* The iron is not introduced in its pure state, as in that case it will not combine with the alloy. It must be added in the form of tinned plate.

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is also thought to give a fine bronze tint, when added in the proportion of two or three per cent. of the entire composition. *Lead* is considered detrimental to bronze, because it is so readily oxidized as to act as a scorifier upon the other metals. Besides this, its great specific gravity causes a precipitation of the copper towards the bottom of alloy, producing irregularities in the casting, especially in large works.

"For many of the uses to which bronze is applied in the arts, its composition is altered; thus, for wheel-boxes or sockets, the alloy contains—

Copper, . .	80
Tin, . . .	18
Zinc, . . .	2
	100

"The fracture of this alloy is nearly white; it has a dry grain, and is very hard, but still may be worked. The zinc is added with the view of preventing cracks, which are apt to form in the casting, owing to the contraction of the alloy upon cooling.

"Another alloy intended for a similar use, and for the collars of motive cylinders, has the following composition:

Copper, . .	82
Tin, . . .	16
Zinc, . . .	2
	100

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"This is somewhat more malleable than the preceding, so that when the collar is being forced on to its place, it is less liable to break.

"An alloy, when required to resist powerful friction and sudden shocks, is made of the annexed proportions:

Copper, . .	83.0
Tin, . .	15.0
Zinc, . .	1.5
Lead, . .	0.5
	100

"For pump-boxes, and such articles as require to be brazed or soldered, the proportions are—

Copper, . .	87
Tin, . .	12
Zinc, . .	1
	100

"This alloy, when broken, presents a reddish fracture, with a fine grain. It is malleable, but not sufficiently so as to answer for the material of stop-cocks, pump-valves, and the like, which are subject to receive concussions, *et cetera*, that would endanger the safety of the article, unless it were sufficiently pliant to resist them. Compositions of this nature contain—

Copper, . .	88
Tin, . .	10
Zinc, . .	.2
	100

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"This alloy has a fine grain, and is capable of receiving a high polish; it has a rich red color."*

Bronze for statues should possess several qualities. It should be capable of flowing into all parts of the mould, however minute; it should be hard, that it may resist accidental blows; it must be of such a composition as to resist the action of the weather, except to the extent of forming upon its surface that greenish coat so much admired in ancient bronzes, and called *patina antiqua*. The brothers Keller, the famous founders of the time of Louis XIV., are celebrated for their success in this kind of statuary. The following tables express the results of the analysis of different statues from their foundry:

	1.	2.	3.	Mean.
Copper,	91.30	91.68	91.22	91.40
Tin,	1.00	2.32	1.78	1.70
Zinc,	6.09	4.93	5.57	5.53
Lead,	1.61	1.07	1.43	1.37
	100.00	100.00	100.00	100.00

The analysis of the statue of Louis XV. gave the following results:

Specific gravity,	8.482
Copper, . . .	82.45
Zinc, ...	10.30
Tin, ...	4.10
Lead, ...	3.15
	100.00

* Muspratt, *op. cit.*

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The properties required in medals resemble those just mentioned as essential to statues. It should be hard enough to resist wear and tear, and yet should possess the opposite property of sensitiveness to the die. The art of tempering enables the manufacturer of medals to combine these two opposite qualities. Modern medals are said to be far less able to resist the oxidizing agencies of the atmosphere than those of ancient coinage. The reason assigned for this is that too much copper is used in the modern works of this kind, and this metal is always softer and more prone to oxidate than an alloy made with a proper amount of tin. The proportion of tin commonly used, varies from seven to eleven per cent., though this sometimes goes as low as four, and rises as high as seventeen per cent. The best proportion is considered to be from eight to twelve per cent., and it is said if two or three per cent. of zinc is added, the bronze tint of the alloy is greatly improved.

Medals are usually cast in fine sand, and finished afterwards by striking them up with a die. Many precautions are requisite to success in the process of casting; but these belong rather to the mechanical than the chemical department of the subject. Suffice it to say, that the sand must be so arranged as to give a sharp impression, and to dry speedily—a property that is obtained, in the first instance, by sprinkling the surface upon which the impression is to be made, with finely powdered charcoal—bone-ash or slate—and in the second, by making the exterior of coarser sand, and having the whole as thin as possible. It is also necessary to obviate the concentration of the casting, which sometimes

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makes a difficulty in the subsequent use of the die. This is effected either by making allowance for this contraction in the mould, which is larger than the die, by the calculated amount of shrinking. An exterior coating of a different metal has been recommended. Lead paper has been suggested; but the inconveniences of working it make it impossible to use it. As a substitute, tinning the model has been resorted to. The coat thus deposited, though very thin, is yet sufficient to make up for the contraction.

These precautions having been observed, the compound metal is fused in a small wind furnace, in crucibles containing ten or twelve pounds each, and is poured into the moulds at such a degree of heat as will not injure their outline. This is a nice point to hit, and the necessary skill can only be acquired by experience. If the metal be too cool it flows badly in the mould; if too hot it acts upon the moisture of the sand, disengaging vapors which give a blistered, irregular appearance to the casting. When it has attained the proper degree of heat, it is coated with a smooth layer of oxide, beneath which the metal is brilliantly white. If the heat be too feeble, the oxide on the surface will be uneven and tarnished; if it be too high, the oxide will fuse and assume, like the metal, a luminous appearance.

The moulds having been filled, the castings should be removed as soon as possible and thrown into water to anneal them. After receiving the impression of the die, they are again heated that they may regain the hardness and durability of bronzes.

It is customary to finish up the medals by giving

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them a surface resembling that of ancient bronzes. This is effected by boiling them in a solution of chloride of ammonium and acetate of copper. A film of oxide of copper is thus deposited upon the surface which varies in depth of color in proportion to its thickness. If the metal be rich in tin, this result is not easily accomplished; but if zinc be present the effect can be easily produced by rubbing its surface with a powder consisting of sand and some copper salt. Sometimes the following ingredients, digested in dilute nitric acid are used; they must be applied with the brush. Common vinegar, ninety parts; sal ammoniac nine, and powdered green one, will give the color of antique bronze. For Florentine bronze, eight parts of alcohol and two of red lead, are digested in dilute nitric acid and applied as above. Another plan is to dissolve in a quart of vinegar three-fourths of an ounce of sal ammoniac, and one and a-half drachms of binoxalate of potash, (salt of sorrel) and to apply to the bright surface of the thoroughly cleansed metal by rubbing with a soft rag or brush till perfectly dry. The process must be repeated till the full effect is obtained.

Dr. Ure recommends for giving an antique appearance, a solution of one part of sal ammoniac, three of cream of tartar, and six of common salt in twelve of hot water, the whole to be mixed with eight parts of a solution of nitrate of copper of specific gravity 1.160. "This compound, when applied repeatedly in a moderately damp place to bronze, gives it in a short time a durable green coat, which becomes by degrees very beautiful. More salt gives it a yellowish tinge, less salt a

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bluish cast. A large addition of sal ammoniac accelerates the operation of the mordant."

Ordnance or Cannon Metal.—This alloy is composed of eighty-eight or ninety parts of copper and ten or twelve of tin, to which proportions the founder generally strictly confines himself. The metals must be absolutely pure, as the smallest quantities of sulphur, lead, iron or arsenic would seriously impair the alloy, perhaps to the extent of rendering the cannon useless. Lead, as has already been stated, renders bronze soft and diminishes its tenacity, and besides the fusion point of such an alloy is so low that the heat developed by the firing of the piece would melt it to such an extent as to occasion inequalities, which would be very dangerous. Sulphur, arsenic or iron would, of course, confer upon the alloy a brittleness totally incompatible with the purposes for which it is to be employed.

Furthermore, the tin itself may be used in such proportions as to produce the faults of over-hardness and want of tenacity. Even when these proportions are exact, a practical difficulty occurs in the casting, owing to the tendeney of the metals to separate according to their specific gravity. This separation occasions serious defects in the guns, as those portions of them which contain excess of tin and are therefore easily fusible, assimilate the sulphur of the gunpowder and give rise to cavities of sulphide of tin, which quickly occasions incrustations. This cause of defect is obviated by cooling the metal to a certain point before allowing it to fall into the mould, and by effecting the hardening within a given time.

It has been ascertained that the same proportions do

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not answer for all pieces of artillery. Thus, eight pounders require only seven and a-half per cent. of tin, while twelve pounders and heavier guns are best made of the proportions already given.

The loss in these castings is very considerable, though by skill and care it may be, in great part, recovered. It is laid down as a rule that to obtain one hundred pounds in the casting, two hundred and twenty pounds must be fused in the furnace. This is distributed as follows:

Weight of casting, ...	100 pounds.
Loss of bronze in the scoria, . .	12½ "
Bronze wasted in the debris, . . .	107½ "
Bronze employed, ...	220 "

Owing to this loss of metal and temporary waste it is evident that the greatest care and skill are necessary for the proper management of the work. Rules have consequently been given for the proper proportioning of the materials used. It is said that, in each charge, one-tenth of its weight of new or ingot copper should be used, and that the tin in the shape of ingots should amount to fifteen per cent. of this. The following quantities are required to produce twenty-two hundred pounds of casting:

Ingot copper, ...	488 pounds.
Ingot tin, ...	73 "
Old pieces of bronze, . . .	1769 "
Bronze in the waste attending the manufacture, . . .	2556 "
Total weight of mixture, . .	4886 "

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The real loss under proper care does not amount to ten per cent., and rarely reaches this point, usually not exceeding six. Cornish or Banca tin is preferred as being freer from lead than most commercial tin. When old tin is used, it is absolutely necessary that it should be subjected to a process of refining before it is introduced into the alloy.

Bell Metal.—The standard composition of bells is seventy-eight of copper and twenty-two of tin, the latter being usually increased to compensate for the loss by oxidation. The founder, however, usually employs other metals to increase the fusibility of the alloy, as well as its cheapness. The admixture of these foreign metals undoubtedly impairs the quality of the product, yet for the reasons just mentioned it is customary to introduce them. A common formula for the manufacture of bells is the following:

Copper,	77
Tin,	21
Antimony,	2
	100

The following analysis by Thomson shows the composition of English bell-metal:

Copper,	80.0
Tin,	10.1
Zinc,	5.6
Lead,	4.3
	100.0

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The founder also often introduces antimony and bismuth in order to give a more crystalline character to the alloy as well as to impart a certain tone to the bells.

Berthier's analysis of the bells of the *pendules*, or ornamental clocks, made in Paris, gave the following results:

Copper, ...	72.00
Tin, ...	26.56
Iron, ...	1.44
	100.00

As in the alloys previously described, so in this, new metal is not always employed. In the working up of the old bell-metals and this, however, it is necessary that their composition should be accurately known, so that the mean of the alloy shall yield a bell of the required quality. In the preparation of the alloy, the whole of the tin is not put in at the beginning, about one-third being reserved for addition when the whole of the bath is in perfect fusion. About one-tenth more than the weight destined for the bell must be melted, this quantity being expended in waste and scorification during the process.

Cymbal or Tam-tam Metal.—Alloys for this purpose are prepared, as already said, from seventy-eight or eighty per cent. of copper and twenty or twenty-two of tin. Newly cast, the alloy of cymbals is grayish white, with a fine close grain. It is very brittle and less fusible than bell-metal. The full sonorous property of the metal is obtained by heating and sudden cooling. The

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fused alloy is cast into moulds, and as soon as the objects have hardened, they are removed and heated to a cherry-red in a furnace. They are then placed between iron discs and plunged into water, where they are allowed to cool. They are then sufficiently tenacious to be worked under the hammer. The instruments, having been thus formed, are now heated and allowed to cool slowly in the air. In consequence of this treatment the vibrations of the metal when struck are stronger, and the sound they emit much louder.

Telescope or Speculum Metal.—The standard of this alloy is:

Copper, ...	66.7
Tin, ...	33.3
	100.0

From this standard, however, as in the other alloys, there is much deviation in practice. The color is steel-white, the alloy is very hard, brittle, and takes a high polish. As its name implies, it is used in the construction of mirrors for telescopes and for other uses.

Edwards, as quoted by Ure, gives, in the Nautical Almanac for 1787, the following directions for making speculum metal:

"The quality of the copper is to be tried by making a series of alloys with tin, in the proportion of one hundred of the former to forty-seven, to forty-eight, to forty-nine, to fifty of the latter metal; whence the proportions of the whitest compound may be ascertained. Beyond the last proportion, the alloy begins to lose in brilliancy

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of fracture, and to take a bluish tint. Having determined this point, take thirty-two parts of the copper, melt, and add one part of brass and as much silver, covering the surface of the mixture with a little black flux; when the whole is melted, stir with a wooden rod, and pour in from fifteen to sixteen parts of melted tin, (as indicated by preliminary trials,) stir the mixture again, and immediately pour it out into cold water. Then melt again at the lowest heat, adding, for every sixteen parts of the compound, one part of white arsenic, wrapped in a paper, so that it may be thrust down to the bottom of the crucible. Stir with a wooden rod as long as arsenical fumes rise, and then pour into a sand mould. While still red-hot, lay the metal in a pot-full of very hot embers, that it may cool very slowly, whereby the danger of its cracking or flying into splinters is prevented."

Tinning Copper.—The process of tinning copper is really the formation of an alloy upon the surface of copper. The vessel to be tinned is heated to the point of fusion of the coating metal, excluding the air to prevent oxidation, and taking measures to bring the surfaces of the two metals in contact. Under these circumstances, combination takes place, provided no other substance intervenes, but as there is usually a thin film of oxide upon all manufactured copper, this must be removed. Sulphuric acid is often employed for this purpose, but the most common agent is chloride of ammonium. The surface of the vessel to be cleansed is sprinkled with this salt in powder, heat is then applied and the powder rubbed over the whole surface. The heat first dissolves and then

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volatilizes the chloride, a portion of it being decomposed to form chloride of copper with the reduced oxide. The chloride is removed by rubbing, leaving a perfectly bright, untarnished surface. The heat being still kept up, tin is laid upon the surface, and the operator, with his pad or cork, rubs it over till the combination is considered complete. The amount of tin deposited was found by Proust to vary from one grain to a grain and five eighths for every square inch of surface. The larger quantity is made up in part of some tin which has not been alloyed with the copper but has simply been solidified upon the surface. This is of no advantage to the purchaser, and being a loss to the manufacturer, it ought to be removed. This is easily accomplished by raising the temperature and pressing well down with the pads, when the excess of tin will flow off.

Sometimes an alloy of tin and lead is used, on account of the greater fusibility of that compound and the greater readiness with which it is applied. This ought not to be used for vessels intended for culinary purposes, as a very small amount of lead, daily introduced into the system, is sufficient to destroy health and life. Proust, it is true, has made some calculations, based upon experiment, by which he undertakes to show that the amount of lead dissolved by the acids of cooking, is very small, even to the extent of being incognizable to ordinary chemical reagents, and that, indeed, the tin of the alloy is alone dissolved, leaving the lead adhering to the vessel easily recognized by its bluish white tint. There must, however, come a time when all the tin will be dissolved and then the lead will necessarily be attacked.

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An improvement in this process has been suggested by Biberal, in which a compound of tin and iron is substituted for pure tin, the proportion of iron, in some instances, rising as high as one to six of tin. The heat must be as high as redness in order to fuse this and keep it melted, while it is applied to the surface. The alloy is applied by placing the end of the ingot upon the heated plate and rubbing briskly with some pressure. When the whole has been treated, the vessel is allowed to cool and any excess or inequality in the tinning is removed by a scraper. The superiority of this application arises from the high degree of heat necessary to melt it, its fusibility, of course, diminishing with the amount of iron alloyed with the tin.

Recovery of Copper from its Alloys.—Our account of the alloys of copper would be incomplete, were we to omit to describe the method by which this metal may be recovered from its compounds. Its separation from tin depends entirely upon the greater oxidability of the latter metal. Fourcroy's method of separation consisted, first, in thoroughly calcining the alloy in a reverberatory furnace, and finely powdering the resulting oxide. A fresh quantity of alloy was then melted in the same furnace, and to it was added one half its weight of the oxide. The temperature was increased and the mixture well incorporated. At the end of a few hours, copper nearly pure rested upon the hearth, and a slag comprising the mixed oxides and some of the earthy matters collected on the surface. This was raked out and the copper tapped into proper moulds. The scoriæ were levigated, and the metallic copper separated by elutriation. By

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this process, 50 pounds of copper, containing only one per cent. of foreign matter, were obtained from 100 pounds of bell-metal.

The washed scoriæ were then intimately mixed with one eighth their weight of pulverized charcoal, and melted in a reverberatory furnace. The result was an alloy of 60 parts of copper and 40 of tin, together with slags richer in tin than those of the previous operation. The alloy thus obtained was roasted and melted in the same furnace. The air sweeping over the surface oxidated the tin more rapidly than the copper, and the surface of the metal was covered with a coat of oxide. This was skimmed off from time to time, till the metal had reached the standard of bell-metal, when it was run out and subjected to the whole process again.

M. Briant improved this process by substituting eliquation for some of the roasting. By fractioning the products flowing off during the process, he obtained, firstly, tin with lead; secondly, tin nearly pure; and lastly, tin alloyed with some copper. The spongy mass which remained on the sole, was treated by oxidation. By this process he not only incurred less loss of tin, but also consumed less fuel and obtained purer products of known composition, applicable directly to the purposes of the arts.

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APPENDIX.

STATISTICS OF COPPER.

The most interesting facts in regard to the production of copper will now be given in a tabular form. The tables are taken from Whitney's Metallic Wealth of the United States, altered by collation with the tables published in Muspratt's Chemistry, and continued from the published accounts of the ticketings at Cornwall and Swansea.

As Great Britain occupies so important a position among the producers of copper, the statistics of her production are first given.

TABLE I.

PRODUCTION OF CORNWALL FROM 1726 TO 1775 INCLUSIVE.

Years.	Tons.	Av'rage price per ton.	Amount	Av'age amt. prod—tons.	Av. annual value.
		£ s. d.	£		£
1726, } 1738, }	64,800	7 15 10	473,500	6,480	47,250
1736, } 1745, }	75,520	7 8 6	560,106	7,552	56,010
1746, } 1755, }	98,790	7 8 0	731,457	9,879	73,145
1756, } 1765, }	169,569	7 6 6	1,243,045	16,970	124,304
1766, } 1775, }	264,273	6 14 6	1,778,337	26,427	177,833

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TABLE II.

PRODUCTION OF CORNWALL FROM 1771 TO 1857, YEAR ENDING JUNE 30.

Years.	Tons of ore.	Tons of copper.	Value in pounds Sterling.	Standard.	Per cent. yield.
1771,	27,896	3,347	189,609	£81 0s.	
1772,	27,965	3,356	189,505	81 00	
1773,	27,663	3,320	148,431	70 00	12
1774,	30,254	3,630	162,000	68 00	
1775,	29,966	3,596	192,000	78 00	
1776,	29,433	3,532	191,590	79 00	
1777,	28,216	3,386	177,000	77 00	
1778,	24,706	2,965	140,536	72 00	
1779,	31,115	3,734	180,906	73 00	
1780,	24,433	2,932	171,231	83 00	
1781,	28,749	3,450	178,789	77 00	12
1782,	28,122	3,375	152,434	70 00	
1783,	35,799	4,296	219,937	76 00	
1784,	36,601	4,392	209,132	72 00	
1785,	36,959	4,434	205,451	71 00	
1786,	39,895	4,787	237,237	75 00	
1787,	38,047	....	190,738	.....	
1788,	31,541	....	150,303	.....	
1789,	33,281	....	184,382	.....	
1790,	.....	....	.....	.....	
1791,	.....	....	.....	.....	
1792,	.....	....	.....	.....	
1793,	.....	....	.....	.....	
1794,	42,816	....	320,875	.....	
1795,	43,589	....	336,189	.....	
1796,	43,313	4,950	356,564	.....	
1797,	47,909	5,210	377,838	.....	
1798,	51,358	5,600	422,633	.....	
1799,	51,273	4,923	469,664	121 00	
1800,	55,981	5,187	550,925	133 03	
1801,	56,611	5,267	476,313	117 05	
1802,	53,937	5,228	445,094	110 18	
1803,	60,566	5,616	533,910	122 00	
1804,	64,637	5,374	570,840	136 05	8.8
1805,	78,452	6,234	862,410	169 16	
1806,	79,269	6,863	730,845	138 05	
1807,	71,694	6,716	609,002	120 00	
1808,	67,867	6,795	495,303	100 07	
1809,	76,245	6,821	770,028	143 12	
1810,	66,048	5,682	569,981	132 05	9.1
1811,	66,499	5,948	563,742	126 00	
1812,	75,510	7,248	608,065	113 00	

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TABLE II.—*Continued.*

Years.	Tons of ore.	Tons of copper.	Value in pounds Sterling.	Standard.	Per cent. yield.
1813,	86,713	8,166	685,572	£113 0s.	
1814,	87,482	7,936	766,825	128 00	
1815,	79,984	6,607	582,108	121 00	9.5
1816,	83,058	7,045	541,737	109 00	
1817,	75,816	6,608	422,426	96 00	
1818,	80,525	6,714	587,977	121 00	
1819,	93,234	7,214	728,032	136 00	
1820,	92,672	7,364	620,347	119 00	
1821,	98,803	8,163	628,832	111 00	8.1
1822,	106,723	9,331	676,285	104 00	
1823,	97,470	8,070	618,933	110 00	
1824,	102,200	8,022	603,878	110 00	
1825,	110,000	8,417	743,253	124 00	
1826,	118,768	9,140	798,790	123 00	
1827,	128,459	10,450	755,358	106 00	7.9
1828,	130,866	9,961	759,175	112 07	
1829,	125,902	9,763	725,834	109 14	
1830,	135,665	10,890	784,000	106 15	
1831,	146,502	12,218	817,740	99 18	
1832,	139,057	12,099	835,812	104 14	
1833,	138,300	11,185	858,708	110 00	8.1
1834,	143,296	11,224	887,902	114 04	
1835,	153,607	12,271	896,401	106 11	
1836,	140,981	11,639	957,752	115 12	
1837,	140,753	10,823	908,613	119 05	
1838,	145,688	11,527	857,779	109 03	
1839,	159,551	12,451	932,297	110 02	7.8
1840,	147,266	11,038	792,758	108 10	7.5
1841,	135,090	9,987	819,949	119 06	7.4
1842,	135,581	9,896	822,870	120 16	7.3
1843,	144,806	10,926	804,445	110 01	7.5
1844,	152,667	11,247	815,246	109 17	7.4
1845,	157,000	12,293	835,350	103 10	7.8
1846,	158,913	12,448	886,785	106 08	7.8
1847,	148,674	11,966	830,739	103 12	8
1848,	155,616	12,870	825,080	97 07	8.3
1849,	144,933	12,052	716,917	92 12	8.3
1850,	150,890	11,824	814,037	103 19	7.8
1851,	154,299	12,199	808.244	101 00	7.9
1852,	152,802	11,706	828,057	106 12	7.6
1853,	180,095	11,839	1,124,561	136 15	6.5
1854,	180,687	11,779	1,153,756	.....	6.6
1855,	195,193	12,577	1,263,739	.....	6.8
1856,	209,305	13,275	1,283,639	.....	..
1857,	289,768	18,915	1,816,644	.....	..

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TABLE III.

This table gives the productiveness of the United Kingdom down to 1835, with accuracy; from that down to 1848, the statement is only approximate, as the British copper cannot be certainly separated from that of foreign origin.

Years.	Tons of copper.	Years.	Tons of copper.
1820,	8,127	1835,	14,470
1821,	10,288	1836,	14,770
1822,	11,018	1837,	10,150
1823,	9,679	1838,	12,570
1824,	9,705	1839,	14,670
1825,	10,358	1840,	13,020
1826,	11,093	1841,	12,850
1827,	12,326	1842.	....
1828,	12,188	1843,	....
1829,	12,057	1844,	14,840
1830,	13,232	1845,	14,900
1831,	14,685	1846,	14,950
1832,	14,050	1847,	13,780
1833,	13,260	1848,	14,720
1834,	14,042		

The above is taken from Whitney, who quotes it from G. R. Porter's Progress of the Nation, London, 1851.

TABLE IV.

Also from Whitney, expressing the productiveness of the new world, approximately in tons of copper.

Years.	Chili.	S America.	Cuba.	U. S. & Canada
1830,	.....	....	0	....
1835,	.....	....	700	....
1840,	9,000	....	4,500	....
1845,	13,270	....	6,800	100
1846,	13,800	....	5,150	150
1847,	11,850	....	4,000	300
1848,	12,275	....	4,000	500
1849,	12,450	....	3,600	700
1850,	.....	1,200	3,400	650
1851,	.....	....	3,400	900
1852,	.....	....	2,600	1,100
1853,	.....	1,300	2,500	2,000
1854,	.....	....	....	....

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TABLE V.

The next table is also taken from Whitney, and gives the productiveness of the world from 1820 down to 1853, in tons of copper.

Years.	Russsia.	Sweden.	Norway.	G. Britain.	Prussia.	Hartz.	Saxony.	Austria.	France.	Spain.	Italy.	Turkey.	Algiers.	Asia.	Australia.	N. Zealand.
1820,	....	....	...	8,127	....	...	..	1,776	137	...	...	....	...	....	....	...
1825,	....	....	...	10,358	....	...	..	2,165	229	...	...	....	...	....	....	...
1830,	3,800	....	...	13,232	838	196	19	2,465	79	...	...	....	...	....	....	...
1835,	....	849	...	14,470	796	220	21	2,657	107	...	...	....	0	....	0	0
1840,	4,600	815	...	13,020	991	...	27	2,695	142	285	...	....	...	.....	450	30
1845,	....	....	642	14,900	955	...	..	2,801	...	...	...	....	...	.....	850	60
1846,	....	....	...	14,950	1,211	...	..	3,310	...	380	250	2,500	500	2,400	1,600	125
1847,	....	....	...	13,780	1,245	...	11	3,309	...	...	...	....	...	....	1,500	50
1848,	4,700	....	...	14,920	1,179	...	38	....	450	...	...	....	...	3,000	2,500	75
1849,	5,550	....	...	13,600	897	...	..	....	...	...	...	....	...	....	3,300	200
1850,	6,450	1,423	567	14,700	1,181	150	51	....	...	...	...	....	...	....	3,500	375
1851,	....	....	...	14,300	....	...	..	....	...	...	...	....	...	....	3,250	...
1852,	....	....	...	14,300	....	...	..	....	...	...	...	450	...	....	2,650	...
1853,	....	....	...	.....	....	...	..	....	...	...	...	....	...	....	....	...

The above are near approximations to the truth for the European countries. The data for Turkey and Asia are very imperfect. The cipher in the columns for Algiers, Australia, and New Zealand, indicates that previous to that time, no ore had been raised in those countries.

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